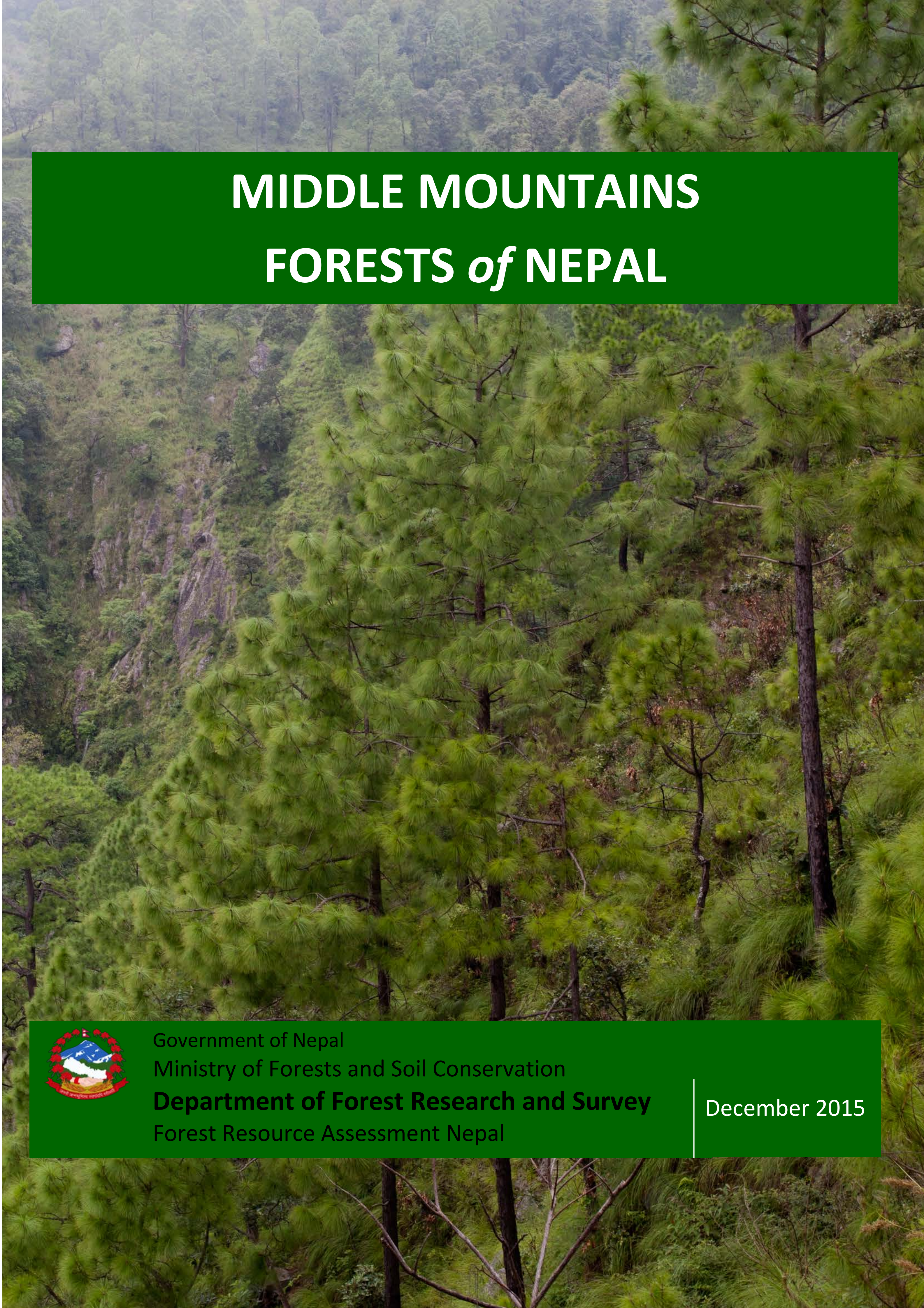

MIDDLE MOUNTAINS FORESTS *of* NEPAL

Government of Nepal

Ministry of Forests and Soil Conservation

Department of Forest Research and Survey

Forest Resource Assessment Nepal

December 2015

MIDDLE MOUNTAINS FORESTS OF NEPAL

FOREST RESOURCE ASSESSMENT NEPAL

DEPARTMENT OF FOREST RESEARCH AND SURVEY

MINISTRY OF FORESTS AND SOIL CONSERVATION

GOVERNMENT OF NEPAL

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FOREWORD

The Government of Nepal implemented the Forest Resource Assessment Nepal (FRA Nepal) project from 2010 to 2014 in cooperation with the Government of Finland. The project aimed to generate forest resource information for supporting policy-making, strategic planning, and international reporting.

All five physiographic regions of the country were covered in this assessment. This report presents the results of the forest resource assessment of the Middle Mountains physiographic region of Nepal. It provides a wide range of information including forest cover, growing stock, and biomass, and forest carbon. Results of the study show that the forest areas of the Middle Mountains have increased since the last assessment period.

I appreciate the hard work of all those involved in planning, field inventory, data analysis, mapping, report writing and other supportive work. I would like to take this opportunity to thank the Government of Finland for providing technical and financial support to undertake this important project.

I believe that this report will be useful to policy-makers, planners, managers, academicians, students and all those with an interest in planning and management of valuable forest resources of the Middle Mountains physiographic region of Nepal.

Uday Chandra Thakur

Secretary

Ministry of Forests and Soil Conservation

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Prakash Mathema

Director General

Department of Forest Research and Survey

ACRONYMS AND ABBREVIATIONS

BRDF	Bidirectional Reflectance Distribution Function
CBS	Central Bureau of Statistics
CCA	Canonical Corresponding Analysis
CCSP	Concentric Circular Sample Plot
CF	Community Forest
CFUG	Community Forest User Group
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DBH	Diameter at breast height (1.3 m)
DCA	DetrendedCorrespondence Analysis
DEM	Digital Elevation Model
DFO	District Forest Office/Officer
DFRS	Department of Forest Research and Survey
DHM	Department of Hydrology and Metrology
DoF	Department of Forests
DoS	Department of Survey
DPR	Department of Plant Resources
FAO	Food and Agriculture Organisation of the United Nations
FRA	Forest Resource Assessment
FRS	Forest Resources Survey
GIS	Geographic Information System
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KS/SK	Khair-Sissoo/Sissoo-Khair
LMH	Lower Mixed Hardwood
LRMP	Land Resources Mapping Project
m^3/ha	Cubic metre per hectare
MFSC	Ministry of Forests and Soil Conservation
MPAD	Medicinal Plants Prioritised for Agro-technology Development
MPFS	Master Plan for Forestry Sector
MPRD	Medicinal Plants Prioritised for Research and Development
MSS	Multi-Spectral Scanner
NDVI	Normalised Difference Vegetation Index
NFI	National Forest Inventory
NTFP	Non-timber Forest Product
OC	Organic Carbon

OL	Other Land
OWL	Other Wooded Land
PA	Protected Area
PSP	Permanent Sample Plot
REDD	Reducing Emissions from Deforestation and Forest Degradation
RMSE	Root Mean Square Error
RS	Remote Sensing
SD	Standard Deviation
SE	Standard Error
SOC	Soil Organic Carbon
t/ha	Tonne per hectare
TMH	Terai Mixed Hardwood
UMH	Upper Mixed Hardwood
USAID	United States Agency for International Development
VDC	Village Development Committee

GLOSSARY

Above-ground biomass	Above-ground biomass refers to the biomass of trees and saplings (≥5cm DBH) above the soil. It includes dead wood but not stumps.
Below-ground biomass	The biomass of trees and saplings (≥5cm DBH) contained within live roots and stumps.
Biodiversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.
Biomass	The biological material derived from living or recently living organisms. It includes both the above- and below-ground biomass of trees and saplings.
Bulk density	Soil mass per unit volume, expressed in g/cm^3.
Canopy cover	The percentage of ground covered by the vertical projection of the foliage of plants.
Carbon pool	Carbon content in above-ground and below-ground biomass, and soil.
CITES (Appendix I)	A list of species whose trade in wild specimens is restricted except for registered scientific research.
CITES (Appendix II)	A list of species that are not necessarily now threatened with extinction but that may become so unless their trade is closely controlled.
CITES (Appendix III)	A list of species whose trade at least one member country has requested other CITES parties for assistance in controlling.
Climber	Any plant that grows by trailing or climbing stems or runners.
Co-dominant tree	A tree with a medium-sized crown at the level of the general canopy which receives full light from above and at least from one side.
Cull tree	A malformed tree that does not meet, and cannot be expected to meet regional merchantability standards.
Dead unusable	A dead tree that cannot be used, even as firewood.
Dead usable	A dead tree that can be used as firewood or for another purpose.
Debris	Fallen dead trees and the remains of large branches (<10 cm diameter) on the forest floor
Dominant tree	A tree whose crown is larger than average and lies at or above the level of the general canopy and receives full light from above and from more than one side.
Dominant species	Species that dominate (comprise >60% of the basal area) an ecological community (e.g. forest).
Forest	An area of land at least 0.5 ha and a minimum width/length of 20 m with a tree crown cover of more than 10% and tree heights of 5 m at maturity.
Frequency	The rate of occurrence of a species within a unit area.

Growing stock	The sum of all trees by number or volume or biomass growing within a unit area.
High-quality sound tree	Live tree which will yield saw logs at least 6 m long at present or in the future.
Intermediate tree	A tree whose crown is smaller than average, reaches the general level of the canopy but not above it, and receives some direct light from above but little, if any, from the side.
Land cover	The bio-physical material covering the surface of the earth.
Land use	The arrangements, activities and inputs people undertake on an area with a certain land-cover type to produce, change or maintain it.
Litter	Dead plant materials such as leaves, bark, needles, and twigs that have fallen to the ground.
Lower Mixed Hardwoods (LMH)	Generally refers to mixed species found between 1,000m to 2,000m.
Non-reachability	Plot is regarded as non-reachable if the slope within the plot is more than 45 degrees (100 %).
NTFPs	Non-Timber Forest Products encompasses all biological materials other than timber, which are extracted from forests for human use.
Other Land	All land that is not classified as Forest or Other Wooded Land.
Other Wooded Land (OWL)	Land not classified as forest spanning more than 0.5 ha, having at least 20 m width and with a canopy cover of trees between 5%and 10%; trees should be higher than 5 m or able to reach 5 m *in situ*. or The canopy cover of trees less than 5% but the combined cover of shrubs, bushes and trees more than 10%; includes area of shrubs and bushes where no trees are present.
Protected Area (PA)	It includes Core Area (National Parks, Wildlife Reserves, Hunting Reserve and Conservation Areas) and Buffer Zone.
Root Mean Square Error (RMSE)	A measure of the differences between values predicted by a model and the values actually observed of the parameter being estimated. Lower the value betters the result/model.
Sal Forest	A forest in which Sal (*Shorea robusta*) comprises more than 60% of the basal area.
Shannon diversity index ($\bar{H}$)	A commonly used diversity index that takes into account both the abundance and evenness of species present in the community.
Shrub	An area occupied by woody perennialplants, generally 0.5–5.0 m at maturity, and often without definite stems or crowns.
Sound Tree	A live tree not qualified as class 1 but with at least one 3 m saw log or two 1.8 m saw logs.
Stratification	Division of an area into homogenous units based on climate, physiography, vegetation, or other characteristics.
Stump	The remnant of a cut or fallen tree.
Suppressed tree	A tree with a crown that is smaller than normal for a tree of its age and size. It receives little or no direct sunlight and shows signs of retarded growth resulting from competition with dominant trees.

Terai Mixed Hardwood (TMH)	A low altitude, broadleaf forest in whichno species contributes 60% of the total basal area. In some situations, this forest type is edaphic but it can also result from selective removal of *Shorea robusta* trees.
Upper Mixed Hardwood (UMH)	Generally refers to mixed hardwood species found above 2,000m.
Understory	A tree with a crown that is below the level of the general canopy and receives little or no direct sunlight though it does not show signs of suppressed or retarded growth.
Wall-to-wall mapping	Mapping that covers an entire area.

MAIN RESULTS

Land Cover

1. Middle Mountains region extend over 4,309,396 ha; Forest covers the greatest proportion (52.30%; 2,253,807 ha), followed by Other Land (46.25%; 1,993,302 ha) and Other Wooded Land, OWL (1.45%; 62,287 ha). Forest and OWL together cover 53.75% of the total land area (2,316,094 ha) in this region.
2. Out of the total 2,253,807 ha of forest area in Middle Mountains, 98.78% falls outside PAs and 1.22% inside PAs (0.74% in Core Area and 0.48% in Buffer Zone).

Growing Stock

3. Middle Mountains region has 2,345.72 million trees with DBH ≥5 cm. Out of which, 1,963.76 million (871.31/ha) is in Forest, 8.37 million (134.45/ha) in OWL and 373.59 million (187.42/ha) in Other Land.
4. Middle Mountains Forests have an average of 7,171 seedlings (height <1.3 m) and 1,167 saplings (height >1.3 m and DBH <5 cm) per hectare.
5. In Middle Mountains, the total stem volume with DBH ≥5 cm is 343.36 million m^3. Out of which, 295.33 million m^3 (131.03 m^3/ha) is in Forest, 0.75 million m^3 (12.00 m^3/ha) in OWL and 47.29 million m^3 (23.72 m^3/ha) in Other Land.
6. In Middle Mountains, the total air-dried biomass of live trees with DBH ≥5 cm is 387.96 million tonnes. Out of which, 340.05 million tonnes (150.88 t/ha) is in Forest, 0.79 million tonnes (12.62 t/ha) in OWL and 47.13 million tonnes (23.64 t/ha) in Other Land.

Soils and Carbon Pool

7. The total carbon stock in Middle Mountains Forests is estimated to be 311.28 million tonnes (138.11 t/ha).

Biodiversity and Disturbance

8. A total of 326 tree species, 244 shrub species, and 547 herb species (including flowering plants and pteridophytes), 109 climber species and 90 epiphyte species were recorded in the sample plots.
9. A total of 868 different species of flora and the derivatives of 72 species of fauna were used as non-timber forest products (NTFPs).
10. About 94% of the sample plots were found to be affected by disturbances. Grazing, *lathra* cutting, tree cutting and lopping were the most common disturbances.

प्रमुख नतिजाहरु

वन क्षेत्र

१. मध्यपहाडी भागको कुल क्षेत्रफल ४,३०९,३९६ हेक्टरमध्ये वनक्षेत्रले २,२५३,८०७ हेक्टर (५२.३०%), अन्य काष्ठ तथा बुट्यानक्षेत्र (Other Wooded Land) ले ६२,२८७ हेक्टर (१.४५%) र अन्य क्षेत्र (Other Land) ले १,९९३,३०२ हेक्टर (४६.२५%) ओगटेको पाइएको छ । यसरी वनक्षेत्र र काष्ठ तथा बुट्यान क्षेत्र दुवैले गरी २,३१६,०९४ हेक्टर (५३.७५%) ओगटेको छ ।

२. कुल वन क्षेत्र मध्ये संरक्षित क्षेत्र भन्दा बाहिर ९८.७८% र संरक्षित क्षेत्रमा १.२२% (भित्री भाग ०.७४% र मध्यवर्ती क्षेत्रको भाग ०.४८%) रहेको पाइएको छ ।

रुखको मौज्दात

३. मध्यपहाडी भागमा कुल जीवित रुख (जमीनबाट १.३ मिटरको उचाईमा कम्तिमा ५ से.मि. व्यास भएका) को संख्या २ अर्ब ३४ करोड ५७ लाख रहेको पाइयो । यस मध्ये वनमा १ अर्ब ९६ करोड ३८ लाख (८७१.३१ प्रति हेक्टर), अन्य काष्ठ तथा बुट्यान क्षेत्रमा करिब ८४ लाख (१३४.४५ प्रति हेक्टर) र अन्य क्षेत्रमा ३७ करोड ३६ लाख (१८७.४२ प्रति हेक्टर) पाइयो ।

४. पुनरुत्पादनको अवस्था मध्यपहाडी क्षेत्रमा औसतमा प्रति हेक्टर विरुवा (उचाई १.३ मि. भन्दा कम) को संख्या ७,१७१ र लाथ्रा (उचाई १.३ मि. भन्दा बढि र ब्यास ५ से.मि. भन्दा कम) को संख्या १,१६७ रहेको पाइयो ।

५. मध्यपहाडी क्षेत्रमा ५ से.मि. र सो भन्दा बढि व्यास (१.३ मि. उचाईमा) भएका जीवित रुखहरूको कुल काण्ड आयतन (stem volume) ३४ करोड ३४ लाख घन मिटर रहेको अनुमान गरियो । कुल आयतनमध्ये वनक्षेत्रमा २९ करोड ५३ लाख घन मिटर (१३१.०३ घन मिटर प्रति हेक्टर), अन्य काष्ठ तथा बुटयान क्षेत्रमा करिब ८ लाख घन मिटर (१२.०० घन मिटर प्रति हेक्टर) र अन्य क्षेत्रमा ४ करोड ७३ लाख घन मिटर (२३.७२ घन मिटर प्रति हेक्टर) पाइयो ।

६. मध्यपहाडी क्षेत्रमा जीवित रुखको कुल जैविक पिण्ड (air-dried biomass) ३८ करोड ८० लाख टन पाइयो । कुल जैविक पिण्ड मध्ये वनक्षेत्रमा ३४ करोड १ लाख टन (१५०.८८ टन प्रति हेक्टर), अन्य काष्ठ तथा बुट्यान क्षेत्रमा करिव ८ लाख टन (१२.६२ टन प्रति हेक्टर), र अन्य क्षेत्रमा ४ करोड ७१ लाख टन (२३.६४ टन प्रति हेक्टर) रहेको पाइयो ।

कार्वनको संचिति

७. मध्यपहाडी वनक्षेत्रमा कुल कार्बनको संचिति करिब ३१ करोड १३ लाख टन (१३८.११ प्रति हेक्टर) रहेको पाइयो ।

जैविक विविधता र मानवीय तथा प्राकृतिक प्रभावहरु

८. मध्यपहाडी वनक्षेत्रमा मापन गरिएका नमुना प्लटहरुमा कुल ३२६ वटा रुख (tree) प्रजाति, २४४ वटा बुट्यान (shrub) प्रजाति र ५४७ वटा झार (herb)प्रजातिहरु रहेको पाइयो ।

९. गैह्रकाष्ठ वन पैदावारको रुपमा ८६८ वटा वनस्पति प्रजाति र ७२ वटा जीवजन्तुका अवयवहरु प्रयोगमा आइरहेको पाइयो ।

१०. मध्यपहाडी वन क्षेत्रका ९४% नमुना प्लटहरुमा प्रतिकूल प्रभावहरु पाइयो जसमध्ये चरिचरन, विरुवा, लाथ्रा र रुख कटानी मुख्य प्रभावहरु रहेका छन् ।

EXECUTIVE SUMMARY

Middle Mountains region occupies 29.2%of the total land area of the country. The elevation of Middle Mountains region varies from 110 m to 3,300 m above mean sea level. Climate of the region ranges from sub-tropical, sub-humid in river valleys to warm-temperate in valleys and cool-temperate in the high hills.

Methodology

In Middle Mountains, forest cover was mapped by adopting a hybrid approach which used automated image classification supported by extensive visual interpretation. Images were classified by applying segmentation and the automated object-based image analysis method.

A two-phased stratified systematic cluster sampling was adopted to conduct the forest inventory. All together 2,723 clusters were laid out systematically at the nodes of 4 km x 4 km square grids across the entire Middle Mountains region of Nepal. These plots were interpreted by using high resolution RapidEye imagery and Google Earth. Out of the total 2,723 clusters, 2,095 clusters occurred in the Forest stratum while the remaining 628 clusters were in the non-forest (Other Wooded Land, OWL and Other Land, OL) stratum. A total of 190 clusters (1,140 plots: 596 Forest, 116 OWL and 428 OL) were selected systematically for field measurement at the second phase. Out of the total 1,140 plots, 267 plots could not be inventoried because of non-reachability. A total of 873 plots (Forest: 433; OWL: 63; and OL: 377), were measured in the field. In each cluster, measurements of tree characteristics, soil samplings, biodiversity and social survey were carried out. Each cluster had six plots and each plot comprised of four concentric circles of different radii, each of which was used to measure trees with a different DBH range.

Forest Cover Mapping

According to forest cover mapping, 52.30% (2,253,807 ha) of Middle Mountains region is covered by Forest and 1.45% (62,287 ha) by OWL, making a grand total of 53.75% covered by Forest and OWL. Out of the total 2,253,807 ha of Forest area in Middle Mountains, 98.78% falls outside PAs, and 1.22% inside PAs (0.74% in Core Area and 0.48% in Buffer Zone).

The average size of forest patches in Middle Mountains (outside of PAs and Buffer Zone) was 59.41 ha. About 58.31% of the total forest patches were less than 2 ha area and 28.25% were 2–10 ha. Only 13.43% of the forest patches were over 10 ha, with 4.92% between 10–20 ha, 3.91%

between 20–50 ha, 1.73% between 50–100 ha, 1.93% between 100–500 ha, 0.26% between 500–1,000 ha, and 0.68% above 1,000 ha.

The results of forest cover mapping were compared with 344 independent ground samples, which revealed an overall accuracy of 72.97%, a Cohen's *Kappa* (κ) of 0.62, and a *Kappa* standard error of 0.03.

Forest Inventory

The total number of stems with DBH ≥5 cm was 2,345.72 million, of which 1,963.76 million (871.31/ha) was in Forest, 8.37 million (134.45/ha) in OWL and 373.59 million (187.42/ha) in OL.

In terms of the number of stems (≥5 cm DBH) per hectare, *Shorea robusta* was the most numerous species (155.46/ha), followed by *Rhododendron* spp.(94.02/ha). In terms of forest types, *Quercus* forests had the greatest number of stems (1,685/ha), followed by Upper Mixed Hardwood forests (1,294/ha). In terms of quality, the average number of stems per hectare was: 150 high-quality sound trees (quality class 1), 225 sound trees (quality class 2), and 496 cull trees (quality class 3). Regarding regeneration, Middle Mountains Forests had an average of 7,171 seedlings (height <1.3 m) and 1,167 saplings (height >1.3m and DBH <5cm) per hectare.

The basal area of stems (≥5cm DBH) was 18.40 m^2/ha in Forest, 2.33 m^2/ha in OWL, and 4.12 m^2/ha in OL. The total stem volume with DBH ≥5 cm was 343.36 million m^3 of which 295.33 million m^3 (131.03 m^3/ha) in Forest, 0.75 million m^3 (12.00m^3/ha) in OWL and 47.29 million m^3 (23.72 m^3/ha) in OL. The standard error of the mean stem volume was 6.29% in Forest. The total stem volume of standing dead trees and dead wood were 2.52 m^3/ha and 6.81 m^3/ha, respectively.

In Middle Mountains, the total air-dried biomass of live trees with a diameter ≥5 cm was 387.96 million tonnes. Out of which, 340.05 million tonnes (150.88 t/ha) was in Forest, 0.79 million tonnes (12.62 t/ha) in OWL and 47.13 million tonnes (23.64 t/ha) in OL. The total air-dried biomass was 195.51 t/ha in Forest, with 157.33 t/ha of the above-ground biomass including deadwood and 38.18 t/ha of the below-ground biomass.

Forest Carbon

The total carbon stock in Middle Mountains Forests was estimated to be 311.28 million tonnes (138.11 t/ha). The tree component contributed 59.47%, litter and debris 1.19%, and soil

39.34%.Upper Mixed Hardwood forests had the highest (100.62 t/ha) and *Shorea robusta* forest had the lowest (37.66 t/ha) SOC values in the Middle Mountains region.

Biodiversity

A total of 326 tree species belonging to 200 genera and 89 families were recorded from the sample plots in Middle Mountains Forests. Similarly, 244 shrub species belonging to 161 genera and 69 families, 547 species of herbaceous plants (including flowering plants and pteridophytes) belonging to 356 genera and 99 families, 109 species of climbers belonging to 60 genera and 30 families, and 90 species of epiphytes with 62 genera and 30 families were recorded.

According to the social survey, a total of 868 species of flora were used as NTFPs in Middle Mountains:283 species of trees, 190 species of shrubs and 291 species of herbs (including sedge), 29 species of ferns and fern-allies and 75 species of climbers. A total of 435 species of NTFPs were used for medicinal purposes. The most commonly used species were *Phyllanthus emblica*, *Terminalia chebula* and *Terminalia bellerica*. Similarly, derivatives of 72 species (60 genera from 36 families) of animals were reported to be used in Middle Mountains. Of them, 28 species were mammals, 34 were birds, two were amphibians, two were reptiles, and six were insects.

Forest Disturbances

Fourteen categories of natural and anthropogenic forest disturbances were observed in the sample plots. Community forest had lower level of anthropogenic disturbance than government managed forests. Livestock grazing was the most common; evidences of tree, pole and sapling cutting was also often encountered. Out of the total instances of disturbance (1,406), 6% had no impact, 42% had minor impact, 34% had medium impact, and 18% had strong impact.

सारांश

मध्यपहाडी क्षेत्रले नेपालको कुल भू-भागको करिब २९.२ प्रतिशत भाग ओगटेको छ । यस क्षेत्र समुद्री सतहबाट ११० मिटर देखि ३,३०० मिटरको उचाईमा अवस्थित छ ।

मध्यपहाडी क्षेत्रको भू-आवरण (Land cover) लाई मुख्यतः वनक्षेत्र (Forest), अन्य काष्ठ तथा बुट्यान क्षेत्र (Other wooded land) र अन्य क्षेत्र (Other land) गरी ३ भागमा वर्गिकरण गरी नक्सांकन गरिएको छ । यस क्रममा RapidEye भू-उपग्रह चित्रहरु र भू-उपयोग तथा आकृति नक्साहरु (जस्तै LRMP mapतथा topographic map) को प्रयोग गरिएको थियो भने वर्गिकरण तथा नक्सांकन कार्यको गुणस्तरीयता र विश्वसनीयता कायम गर्न फिल्ड प्रमाणीकरण (field verification) को अतिरिक्त Google Earth चित्रसंग समेत तुलनात्मक अध्ययन गरिएको थियो ।

वनस्रोत सर्वेक्षणको लागि पहिलो चरणमा मध्यपहाडी क्षेत्रभरि ४ कि.मि. X ४ कि.मि. को दुरी कायम गरी जम्मा २,७२३ वटा नमुना सर्वेक्षण ठाउँ (field sample cluster) पहिचान गरिएको थियो । जसमध्ये २,०९५ ठाउँहरु वन क्षेत्रमा र ६२८ ठाउँहरु वनक्षेत्र बाहिर परेको थियो । सर्वेक्षणको दोस्रो चरणमा १९० वटा ठाउँहरुमा जम्मा १,१४० नमुना प्लटहरु छानिएको थियो, ती प्लटहरु मध्ये ५९६ वटा वनक्षेत्र (Forest) मा, ११६ वटा अन्य काष्ठ तथा बुट्यान क्षेत्रमा र ४२८ वटा अन्य क्षेत्रमा परेको थियो । वनक्षेत्रभित्रमा ४३३ नमुना प्लटहरु, अन्य काष्ठ तथा बुट्यान क्षेत्रमा ६३ वटा र अन्य क्षेत्रमा ३७७ वटा गरी जम्मा ८७३ नमुना प्लटहरुको मात्र स्थलगत नाप पैमाइस (field measurement) गरिएको थियो । प्रत्येक नमुना प्लटमा ४ वटा वृत्ताकार प्लटहरु (concentric circular sample plot) स्थापना गरी केन्द्रबाट ४, ८, १५ र २० मिटरका वृत्तीय घेराहरु बनाएर रुखको आकार अनुसार नाप पैमाइस गरिएको थियो । नमुना नापी प्लटभित्र पर्ने गरी बुट्यान प्रजाति र गैरकाष्ठ प्रजातिहरुको मापन र प्लटको चारवटा बाहिरी कुनाबाट माटोको नमुना संकलन समेत गरिएको थियो ।

भू-उपयोग नक्सांकनको आधारमा मध्यपहाडी क्षेत्रको करिब ५२.३०% (२,२५३,८०७ हेक्टर) भू-भाग वन क्षेत्रले ओगटेको देखिन्छ भने अन्य काष्ठ तथा बुट्यान क्षेत्र र अन्य क्षेत्र क्रमशः करिब १.४५% (६२,२८७ हेक्टर) र ४६.२५% (१,९९३,३०२ हेक्टर) भू-भागमा विस्तारित छ । सर्वेक्षणबाट मध्यवर्ती क्षेत्रमा करिब ०.४८% र भित्री क्षेत्रमा ०.७४% गरी मध्यपहाडमा संरक्षित क्षेत्रभित्र करिब १.२२% वन रहेको देखिन आउछ भने बाँकि ९८.७८% वनको भू-भाग सरंक्षित क्षेत्र वाहिर रहेको छ ।

वनको अवस्था आंकलन गर्दा मध्यपहाडी क्षेत्रमा प्रति हेक्टर औसत विरुवा (seedling) को संख्या करिब ७,१७१ र औसत लाथ्रा (sapling) को संख्या करिब १,१६७ रहेको छ । रुखको प्रति हेक्टर औसत संख्या ८७१ देखिन आएको छ भने रुखहरुको १.३ मि. उचाइमा लिएको क्षेत्रफल (basal area) १८.४० वर्ग

मिटर प्रति हेक्टर रहेको छ। यसैगरी वनक्षेत्र, अन्यकाष्ठ तथा बुट्यान क्षेत्र र अन्य क्षेत्रमा रुखको आयतन (stem volume) औसतमा क्रमशः १३१.०३, १२.०० र २३.७२ घन मिटर प्रति हेक्टर देखिन आउँछ। रुख प्रजातिको आधारमा हेर्दा रुखको प्रति हेक्टर औसत आयतन सबैभन्दा बढि साल प्रजातिमा पाइएको छ भने त्यसपछि सल्ला प्रजाति र सबैभन्दा कम खयर प्रजातिमा पाइएको छ। मध्यपहाडको वनमा औसत कार्वन संचिति करिब १३८.११ टन प्रति हेक्टर अनुमान गरिएको छ, जसमा रुख, माटो र पातपतिंगर(litterand debris) को योगदान क्रमशः ५९.४७%, ३९.३४% र १.१९% रहेको छ।

नमुना सर्वेक्षणको क्रममा मध्यपहाडमा कुल ३२६ वटा रुख प्रजाति (२०० जाति र ८९ परिवार), २४४ वटा बुट्यान (shrub) प्रजाति (१६१ जाति र ६९ परिवार), ५४७ वटा झार (herb) प्रजाति (३५६ जाति र ९९ परिवार) र १०९ वटा लहरा प्रजाति तथा ९० प्रजातिका इपिफाइटिक (अरुको सहारामा बाँच्ने) विरुवाहरु पाइएको छ। गैरकाष्ठ वन पैदावारको रुपमा ८६८ प्रजातिका वोटविरुवा र ७२ प्रजातिका जीवजन्तु र तिनका अंगहरु प्रयोगमा आएको अध्ययनबाट देखिएको छ।

मानवीय क्रियाकलापको आधारमा मध्यपहाडी क्षेत्रको सामुदायिक वनमा सरकारद्वारा व्यवस्थित वन र निजी वनको तुलनामा मानवीय तथा प्राकृतिक प्रभावहरुको चाप कम रहेको पाइयो। मध्यपहाडी वन क्षेत्रका कुल ४३३ नमुना प्लटहरु मध्ये ९% मा मानवीय तथा प्राकृतिक प्रभाव नपरेको, ४२% मा न्यून प्रभाव, ३४% मा मध्यम प्रभाव र १८% मा बढि प्रभाव परेको पाइयो। सर्वेक्षणमा संलग्न १४ किसिमका प्रभावहरु मध्ये मध्यपहाडी वन क्षेत्रमा मुख्य रुपमा चरिचरन, विरुवा, लाथ्रा र रुख कटानी पाइएको छ।

TABLE OF CONTENTS

1. INTRODUCTION

Middle Mountains, also known as the Mid Hills, lie north of Churia along the southern flanks of the Himalayas (Figure 1). The Main Boundary Thrust (MBT) serves as the border between the Churia and southern Middle Mountains, the uplifted Mahabharat Range (LRMP, 1986). It was formed in the Precambrian and Paleozoic periods and is predominantly composed of schist, phyllite, gneiss, quartzite and limestone belonging to the Lesser Himalayan Zone (Upreti, 1999). The northern region of Middle Mountains known as Midland, in contrast, consists of those regions of the Lesser Himalayan geological zone which are thrust over Churia Group along the Main Boundary Thrust. This region is primarily composed of schist, phyllite, gneiss, quartzite, granite, limestone and dates back to the Precambrian and Paleozoic to Mesozoic periods belonging to the Lesser Himalayan Zone.

The region occupies 4,306,230 ha (29.2%) of the total land area of the country and covers parts of 55 of the nation's 75 districts. The elevation of Middle Mountains region varies from 110 m in the lower river valleys to 3,300 m above mean sea level in the hill of Mahabharat range. The region is characterised by rugged landscape and steep slopes terraced for cultivation.Middle Mountains has the greatest ecosystems and species biodiversity (MFSC, 2002).

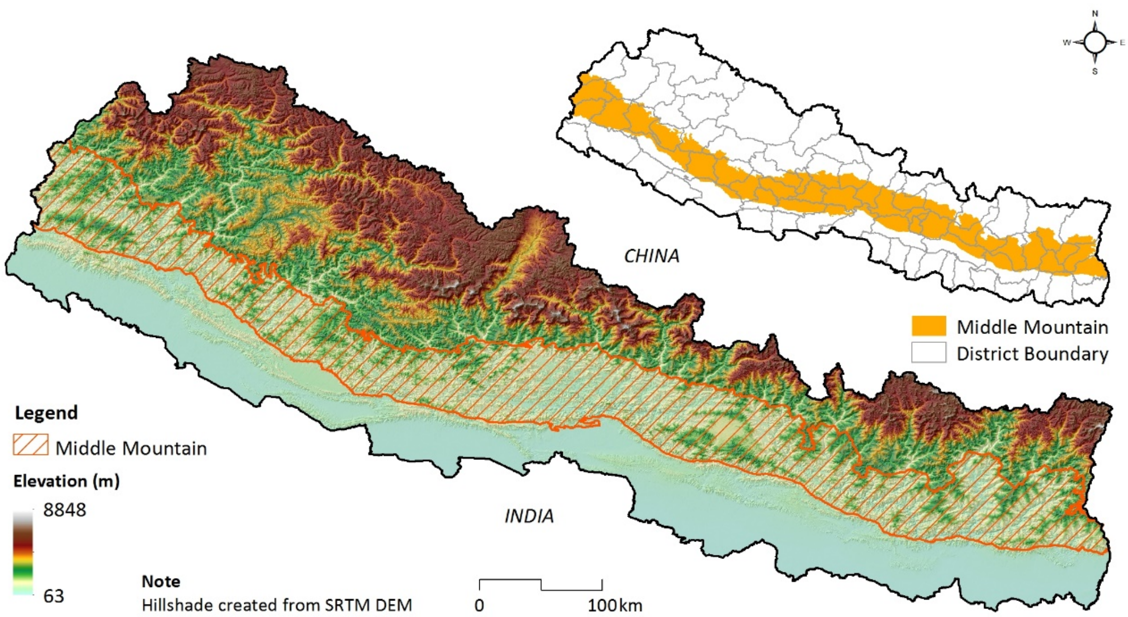


Figure 1: *Extent ofMiddle Mountains of Nepal*

1.1 Practice of Forest Management in Middle Mountains

Since 1978, the Community Forestry (CF) development programme has helped change the landscape of Middle Mountains using indigenous forest management systems as its foundation. A total of 1,700,048 ha of forest in Nepal is managed by over 18,000CFUGs (DoF, 2014). The greatest proportion of land and CFUGsare located in Middle Mountains (DoF, 2014).

CF is regarded as successful forestry programmes in Middle Mountains to improve forest condition, increase forest productivity, increase forest coverage ondegraded land, improve the livelihoods of the local people, and increase support for community development (Springate-Baginski *et al*., 1999 and 2003; Malla, 2000; McNeely, 2002). To sustain this and other initiatives, the Government prepared theMaster Plan for Forestry Sector (MPFS) to reflect the involvement of local communities in forest management (MPFS, 1989). The MPFSdeclared that all accessible forests in Middle Mountains should be handed over to CFUGs and that DoF staff should be reoriented toward this new priority. It also allocated 47% of investment inthe forestry sector to CFprogrammes (Springate-Baginski*et al.* 2003). Local communities were involved in the plantation of degraded land in the Middle Mountains with the support of different organisations. Nepal Australia Community Forestry Programme (NAFP), for example, supported the establishment of more than 20,000 ha of plantation in Sindhupalchok and Kavredistricts (Collett *et al.,* 1996).

After the reinstatement of multi-party democracy in the country in 1990, a number of new forestry laws were promulgated in Nepal to promote forest management by giving communities full rights to the protection offorests from degradation and to themanagement and sustainable utilisation of forest resource. The Forest Act of 1993 and Forest Regulationsof 1995 provided the legal and procedural basis for CFUGs to become local-level autonomous forest management bodies. The Forestry Sector Policy (2000) then strengthened the CF programme. The tenth five-year plan(2002–2007)focused on the conservation and sustainable use of forest resources, poverty reduction through participatory approaches, and providing income generation and employment opportunities (HMGN, 2002). The thirteenth plan (2013/14–2015/16) also emphasises sustainable forest management (NPC, 2013). It focuses on ensuring easy availability of forest products, employment generation and livelihood improvement through commercialisation and proper use of forests products and ecosystem services.

Despite continuous support for sustainable forest management, most CFUGs have yet to move beyond protection-oriented activities. CF operational plans do not fully utilise resource potentials ormeet all user needs and even planned operations are not fully implemented (Aryal*et al*., 2014). Instead, CFUGs extract only a minimal quantity of forest products, making protection their utmost priority (NPC, 2001; Shrestha, 2000).There is a need to develop sound silvicultural tools so that CFUGs can meet their needs of multiple forest products (timber and non-timber) and ecosystem services (Aryal, 2014). A review of 30 years of CF which demonstrated that it had brought about several important areas of social and political change as well as impressive gains in natural resources (MSFP, 2013).It concluded thatto increase the efficiency of resource utilisation and multiple benefits, CFsare in need of technical forest management strategies. Moreover, information on the status of Middle Mountainsforests is highly valuable for long-term planning.

1.2 Population

Historically, this region has been the most populated region of the country with high population densities in major urban centres, including Kathmandu Valley and Pokhara, and relatively low densities in many towns and villages in river valleys and in the hills. The population in Middle Mountains is about 10.45 million, or 41% of the total population of the country.Its 2.45 million households comprise 45% of the total households in the country. The average population density is about 550 individuals/km^2 and the average household size is 4.81 individuals. The proportions of females and males are 53% and 47%, respectively.

Most of the population lives in Central Development Region (40%) followed by Western (24%), Eastern (15%), Mid-Western (13%) and Far-Western Region (9%). The population density is also highest in Central Development Region followed by Western, Far-Western, Mid-Western and Eastern Regions (Table 1).

Table 1: *Population characteristics of Middle Mountains district by Development Region*

Region	Male (no.)	Female (no.)	Total population (no.)	%	Household (no.)	Average household Size (no.)	Population density (persons/ km^2)
Far-Western	**456,912**	**532,144**	**989,056**	**9.11**	**185,969**	**5.38**	**270**
Mid-Western	**641,035**	**733,946**	**1,374,981**	**12.67**	**272,426**	**5.19**	**224**
Western	**1,158,587**	**1,448,074**	**2,606,661**	**24.02**	**632,725**	**4.26**	**376**
Central	**2,126,929**	**2,166,450**	**4,293,379**	**39.57**	**1,013,317**	**4.51**	**1,671**
Eastern	**744,753**	**842,230**	**1,586,993**	**14.63**	**345,932**	**4.69**	**208**
Total	**5,128,216**	**5,722,844**	**10,851,070**		**2,450,369**	**4.81**	**549.60**

Source: CBS (2011)

1.3 Climate

The climate in Middle Mountains ranges from sub-tropical in river valleys to warm-temperate in valleys to cool-temperate in the high hills. The average annual maximum temperature[1] is about 23.5°C (ranging from 5°C to above 40°C); and the average annual minimum, 12.7°C (ranging from -3°C to 30°C). Annual precipitation[2] varies from east to west with the highest in Western Development Region (1,898mm), followed by Far-Western (1,410 mm), Mid-Western (1,389 mm), Eastern (1,260 mm) and Central Regions (1,091 mm) (Figure 2).

Middle Mountains are the first great barrier to monsoon clouds and high precipitation occurs on the southern slopes of the mountains. The conditions support lush vegetation with plenty of climbers and epiphytes. The warm-temperate monsoon climate occurs in the lower part of Middle Mountains, from approximately, 1,000 to 2,000 m, while the upper part, between 2,000 to 3,000 m, has cool-temperate monsoon climatic conditions (Acharya, 2003).

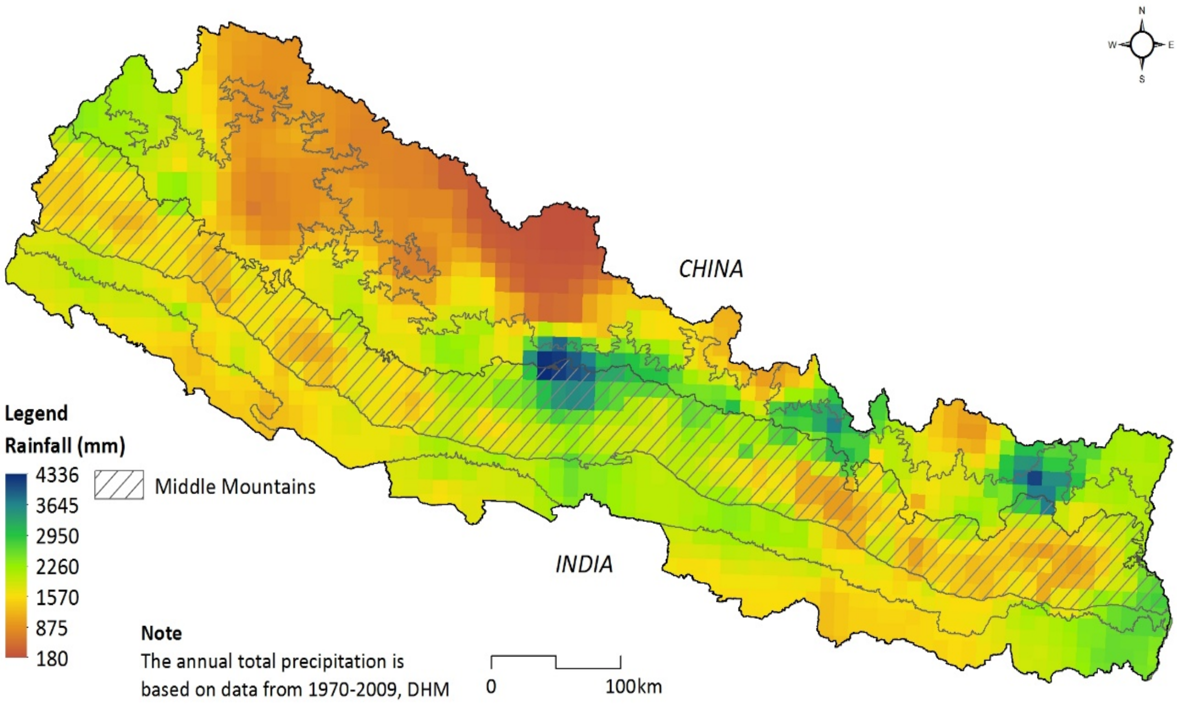


Figure 2: *Total annual precipitation (1970-2009, DHM)*

[1]Temperature data is based on the average monthly temperatures (1953–2013) at 66 stations of Department of Hydrology and Metereology (DHM).

[2]Precipitation data is based on the total average precipitation (1971–2013) at 63 DHM stations.

1.4 Geology and Soils

Middle Mountains range is cut in many places by antecedent rivers such as Koshi, Gandaki (Narayani), Karnali, and Mahakali. Schist, phyllite, gneiss, quartzite, granite and limestone parent rocks occur in the range, geologically belonging to the Lesser Himalayan Zone (Upreti, 1999). The valleys of Middle Mountains region, below the steep slopes, have alluvial loamy and sandy soils. On higher slope positions, the loam is mixed with boulders and exposed bedrock (Dijkshoorn and Huting, 2009).

The area is partly covered by glacial deposits formed during the last ice age. Such soils may become unstable when wet. Because of the steep slopes and dynamic geological conditions, large scale landslides are common in the area during the monsoon, especially where the soil has been exposed by roads and agricultural terracing.

Mountain forests are typically rich in soil organic carbon (SOC). Since litter and woody debris collection has an important role in communities. It is possible that in most densely populated areas the above-ground litter input into soil carbon pool may be reduced. On the other hand, below-ground input of fine root turnover can sustain the most important carbon input to the soil pool. Forest degradation or conversion to cropland in Middle Mountains constitutes the greatest threat to carbon pools both above-ground and in the soil. The organic rich, loose surface layer of soil can be easily eroded by rains.

1.5 Drainage

The major river systems in the region are the Babai, West Rapti, Tinau, Bagmati, Kamala, Kankai, and Mechi (Figure 3). These rivers, originating in the Lesser Himalaya and the Mahabharat Range, are called second-grade rivers. They are fed by precipitation as well as ground water recharge, including that from springs (WECS, 2011). These rivers are perennial and are commonly characterised by wide seasonal fluctuation in discharge.

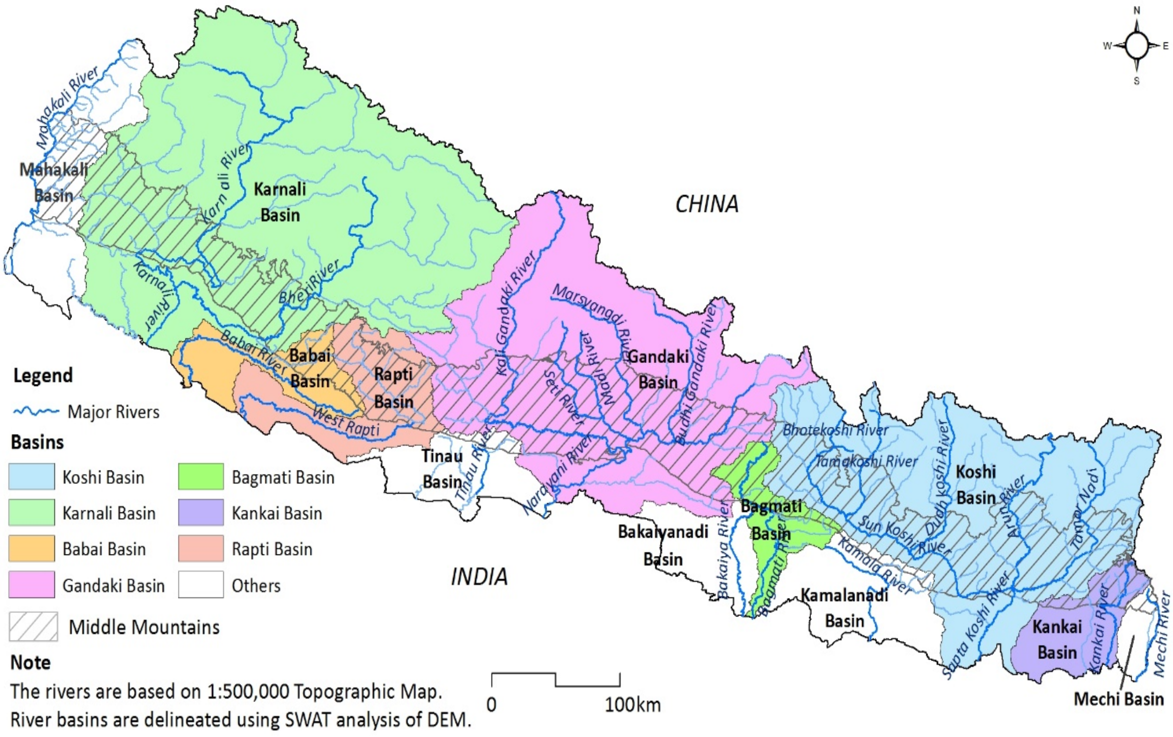


Figure 3: *River basins and drainage systems of Nepal*

2. PREVIOUS FOREST RESOURCES ASSESSMENT

The first national-level forest inventory was carried out in the 1960s. Since then, several forms of forest resource assessments have been carried out, each different in terms of purpose, scale, scope, design and technology used. The second national-forest inventory was carried out in 1990s. FRA Nepal (2010–2014) is the third and most comprehensive national-level forest resource inventory that has been carried out.

2.1 Forest Resources Survey (1963–1967)

The first national-level forest inventory was conducted between 1963 and 1967 with support from USAID (FRS, 1967). It covered areas classified as the Terai, Inner Terai and Churia Hills, as well as thesouthern faces of the Mahabharat Range but excluded most of the then Chitwan Division, which was inventoried separately. After classifying forests as either commercial or non-commercial, the survey focused on collecting data from commercial forests, primarily on timber estimates of stock and the domestic consumption of wood products. Methodologically, it used the visual interpretation of aerial photographs taken in 1953–1958 and again in 1963–1964, mapping, and field inventory. The inventory provided the first comprehensive assessment of commercial forests in the Terai as well as those in adjoining areas and in the hilly region.

2.2 Land Resources Mapping Project (1977–1979)

Land Resources Mapping Project (LRMP) was a whole-country assessment which used a variety of methods, including interpretation of aerial photographs taken between 1977 and 1979, topographic maps and ground verification. It focused on mapping land cover and land use, producing forest cover maps and assessing the type, size and crown cover of forests. Both high- and low-altitude forests were mapped by crown cover (0–10%, 10–40%, 40–70%, and 70–100%); scrubland was mapped separately. Each forest was defined on the basis of dominant species and forest type (coniferous, hardwood, or mixed). Land use maps at the scale of 1:50,000 were produced using aerial photographs with a scale of 1:12,000.

2.3 National Forest Inventory (1987–1998)

The Second National Forest Inventory (NFI) was conducted by the Department Forest Research and Survey (DFRS) with support from the Government of Finland from 1987 to 1998. Using 1991 Landsat TM satellite images of the Terai and aerial photographs of the hills taken in 1989–1992

(DFRS, 1999), it updated data on forest coverage as well as forest statistics for all accessible forests, excluding those in protected areas. The NFI categorised Middle Mountains region as the Hilly Area in general. Three types of inventories were carried out: using Landsat TM satellite imagery for 14 districts, a district-wise forest inventory for 10 districts, and aerial photo interpretation for 51 districts. District-wise forest inventory data was used to estimate the forest and shrub cover in the Middle Mountains. In the hills, photo-point sampling was used to estimate forest area as well as to carry out forest inventory in the field. Forestland was defined as an area of at least one hectare with a crown cover of 10% or more.

3. METHODOLOGY

3.1 Land Cover Area

Forest cover maps were prepared by using RapidEye MSS satellite imagery (Level 1b, 48 scenes acquired in February and March 2010/11), secondary images (Google Earth images, Landsat, etc.), ancillary maps (LRMP and topographical maps) and the FRA Nepal field inventory data. The imageries were processed for geometric and atmospheric corrections prior to forest cover analysis and mapping (DFRS/FRA, 2014).

Area by land cover classes—Forest, Other Wooded Land (OWL), and Other Land (OL)—was estimated by using the forest cover maps. Also, the results on area by protection category, area by districts, and forest patches were estimated by using the forest cover maps.

3.2 Analysis of Remote Sensing Data

Forest Cover Maps were prepared by using RapidEye MSS Satellite Imagery (Level 1b, radiometrically corrected), secondary images (Google Earth images), ancillary maps (LRMP and topographical maps) and the FRA Nepal field inventory data.

Geometric Correction of Satellite Images

The RapidEye Level 1b imagery (25 scenes acquired in Februrary–April 2010/11) was ortho-rectified by using Toutin's Model (Toutin, 2004), with ground control points and digital elevation model. The ground control points were collected by using road and river features and the digital elevation model, generated using contours and spot levels from the National Topographical Base Map Data. Independent check points were collected to assess the level of accuracy (Figure 4). The planimetric accuracy of the ortho-rectified images was 9.81 m (≈1.96 pixels RMSE) for the 1,355 ground-control points collected for 48 RapidEye scenes covering the entire nation.

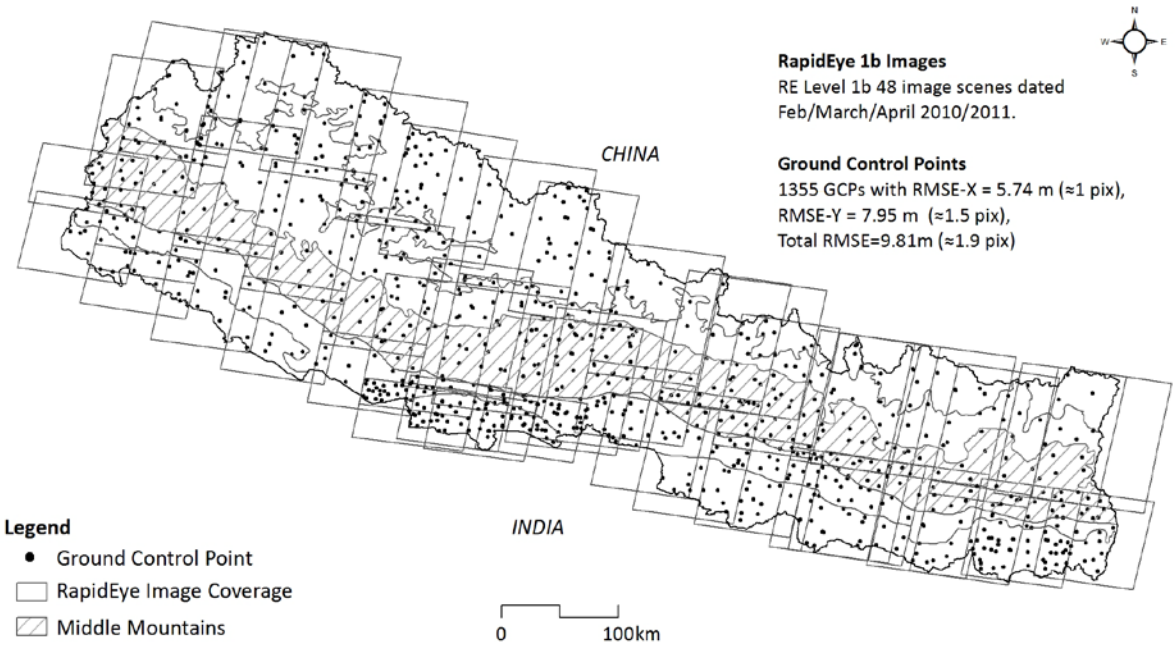


Figure 4: *RapidEye image tiles and ground control points used for mapping*

Atmospheric Correction of Satellite Images

Atmospheric correction was made to minimise the effects of atmospheric haze and terrain shadows using topographical normalisation and Bidirectional Reflectance Distribution Function (BRDF) correction of the ATCOR3 model (Figure 5), defined by Richter (1998) and given in Equation 1.

Equation 1:*Bidirectional Reflectance Distribution Function (BRDF)*

$$G = (\cos\beta_i / \cos\beta_T)^{1/2}$$

Where,

G = BRDF factor

β_i =incidence angle

β_T =threshold angle

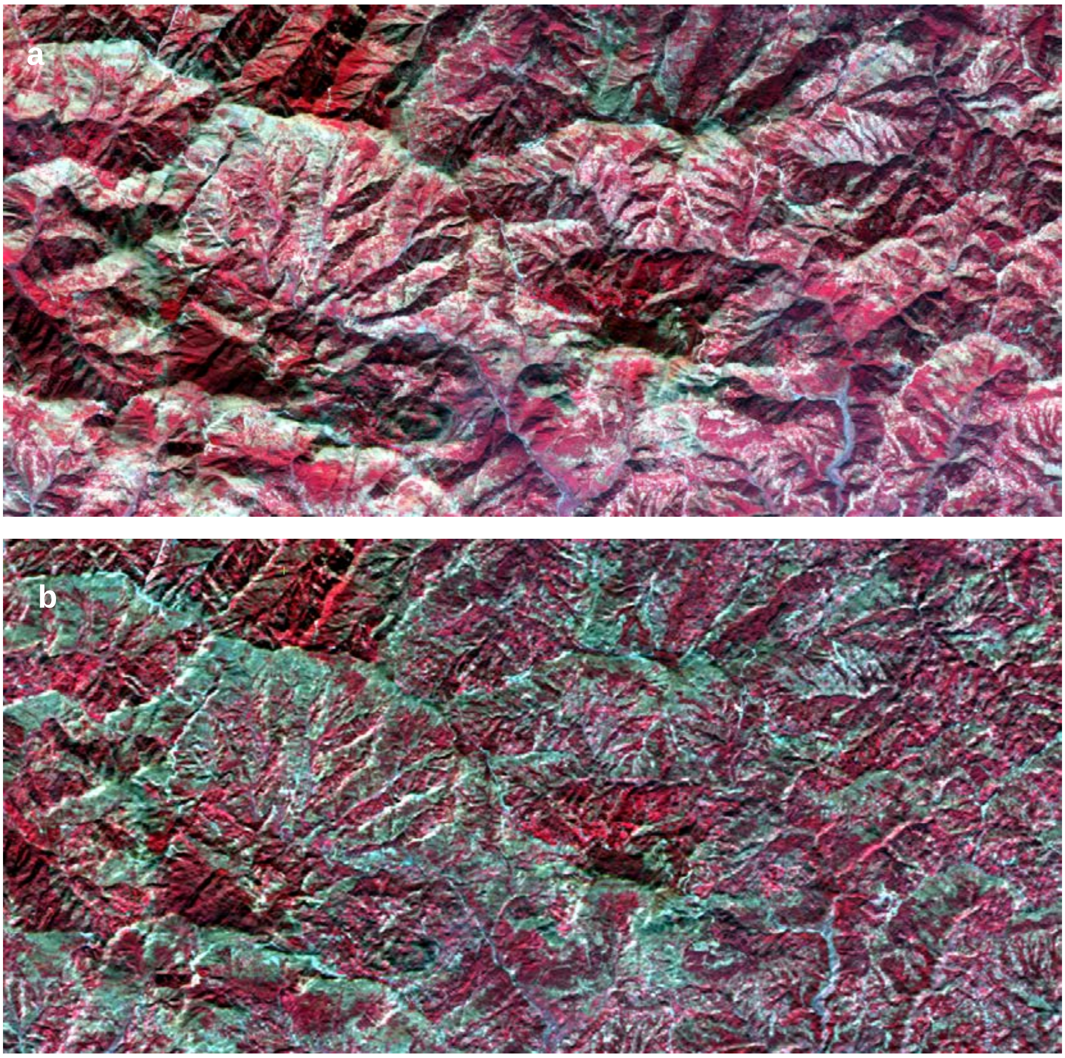


Figure 5:*Atmospheric correction; (a) Image before and (b) after atmospheric and BRDF corrections in Central Middle Mountains*

3.3 ForestCover Mapping

Forest cover was mapped by adopting a hybrid approach using both automated image classification system and supported by extensive visual interpretation (GOFC-GOLD, 2013). Images were classified by applying segmentation and the automated object-based image analysis method (Baatz and Schape, 2000) using eCognition software (Version 8). Four spectral properties were considered: (i) mean pixel values of green, red, red-edge and near-infrared bands; (ii) a derived Normalised Difference Vegetation Index (NDVI); (iii) principal components; and (iv) the homogeneity texture of the near-infrared band. Randomly sampled reference training sets from the Phase 1 plots were used to classify land as Forest, OWL and Other Land (non-forest) along with additional field observation data for OWL and shrub classification. Forest, OWL and Other Land areas were classified by defining a 'containment membership function' for threshold values for all four properties. In order to improve classification accuracy, on-screen post-classification visual interpretation was carried out on the classified Forest, OWL (including shrub) andOther Land areas by using high resolution images in Google Earth. In addition, map verification was undertaken throughout the Middle Mountains region, in order to delineate OWL (including shrub) as well as to rectify errors in forest cover classification.

The accuracy of the forest cover map was assessed by comparing the area classified as Forest with 190 randomly selected FRA inventory plots and 154 additional purposively observedsample plots for Other Wooded Land and Shrub in field.

Forest Patch Mapping

The forest patches and the sizes of those patches were analysed and mapped. Spatially contiguous forest patches outside PAs that fulfilled the criteria for forest were categorised based on their sizes, which ranged from less than 2 ha to greater than 50,000 ha. The frequency of occurrence and total area covered in each size category were analysed to assess the distribution and area of forest fragments.

Distribution of Middle Mountains Forests by Slope Class

The slopes of forests were spatially analysed by using a digital elevation model (DEM)[1] created from the national topographic dataset (DoS, 2001). The elevations of each forest pixel (rasterised at a pixel size of 20 m) created from the classified forest cover by using RapidEye images were classified into slope groups of <15% (<8.5^{o}), 15–35% (8.5–19.0^{o}), 35–60% (19.0–31.0^{o}), 60–100% (31.0–45.0^{o}), and >100% (>45^{o}) to produce a forest slope map of the Middle Mountains. The total forest area under each slope class was also calculated.

3.4 Forest Inventory

FRA Nepal adopted a hybrid approach in forest inventory by using interpretation of satellite imagesat first stage and the measurement of forest characteristics in the field at second stage. These methods are described below.

[1]ADEM at 20 m resolution was created using the contours of the national topographic maps and spot height datasets using the ANUDEM algorithm.

Forest Inventory

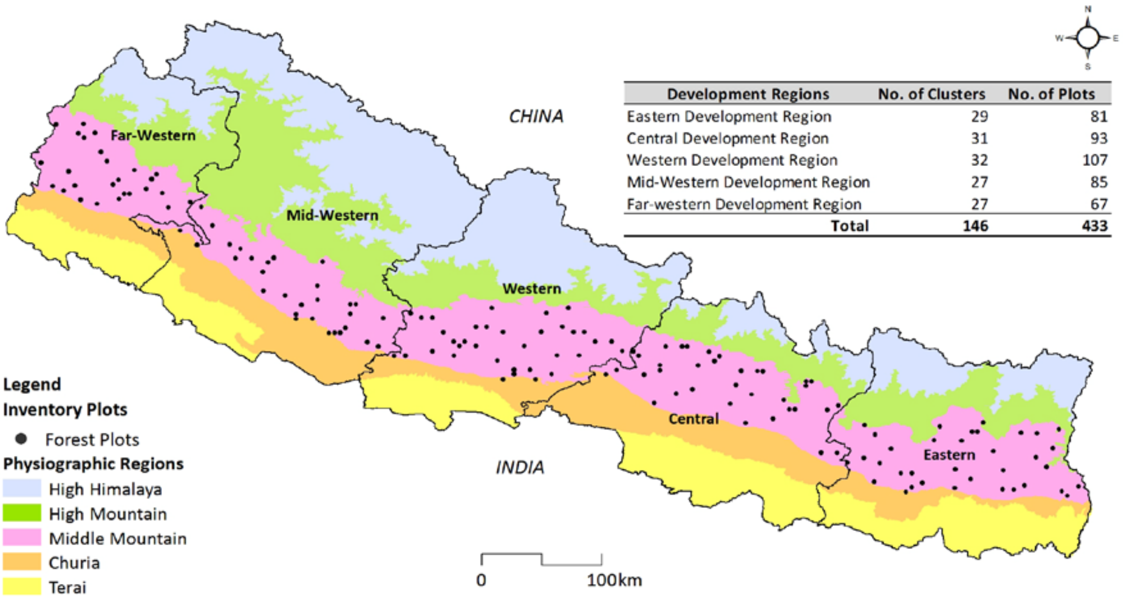
The inventory design was largely based on the principle adopted for NFI (1999) developed by Kleinn (1994). The design was tested in the field and subsequently revised to improve its functionality. Two-phased systematic cluster sampling design was adopted for field data measurement.

Sampling Design

A two-phased systematic cluster sampling design was adopted. In the first phase, a 4 km× 4 km grid was superimposed on a high-resolution RapidEye (5m spatial resolution) satellite image covering the entire country with the help of Google Earth images and topographic maps to create 9,180 clusters (grid-cells), each of which consisted of six concentric circular sample plots, thereby making a total of 55,358 sample plots (Figure 6) to be visually analysed.The 16,139 sample plots in 2,723 clusters falling in Middle Mountains[1] physiographic region were visually interpreted by using standardised procedures (DFRS/FRA, 2014). These plots were 300 m apart in east-west direction, whereasplots were laid out at 150 m apart in north-south direction to capture higher variability of forest characteristics along the altitudinal gradient (Figure 7).Starting in the southwest of Far-Western Nepal, the clusters were systematically numbered from south to north and west to east.

The 2,723 clusters in Middle Mountains were divided into threestrata. Clusters in the first stratum had at least threeplots (out of six) with forest land;clusters in the second stratum had either one or two plots (out of six) with forest land. These were known as forest clusters and totalled 2,095. The remaining 628 clusters were categorised as third stratum (non-forest). For field sampling, every 12thwas selected for the firststratum (117 out of 1,419 clusters) and every 18th for the second stratum (37 out of 676 clusters) as well as the third (36 out of 628 clusters) stratum.

[1] The stratification of physiographic boundaries was based on a general physiographic (1:500,000) map produced by the LRMP.



Development Regions	No. of Clusters	No. of Plots
Eastern Development Region	29	81
Central Development Region	31	93
Western Development Region	32	107
Mid-Western Development Region	27	85
Far-western Development Region	27	67
Total	**146**	**433**

Figure 6:*Distribution of permanent sample clusters in Middle Mountains region*

Of the 1,140 plots, 596 were in Forest, 116were in OWL and 428 in Other Land.Of the total, 267plots could not be inventoried because of nonreachability. Out of 873 measured plots, 433 were in Forest, 63 in OWL and 377 in Other Land.

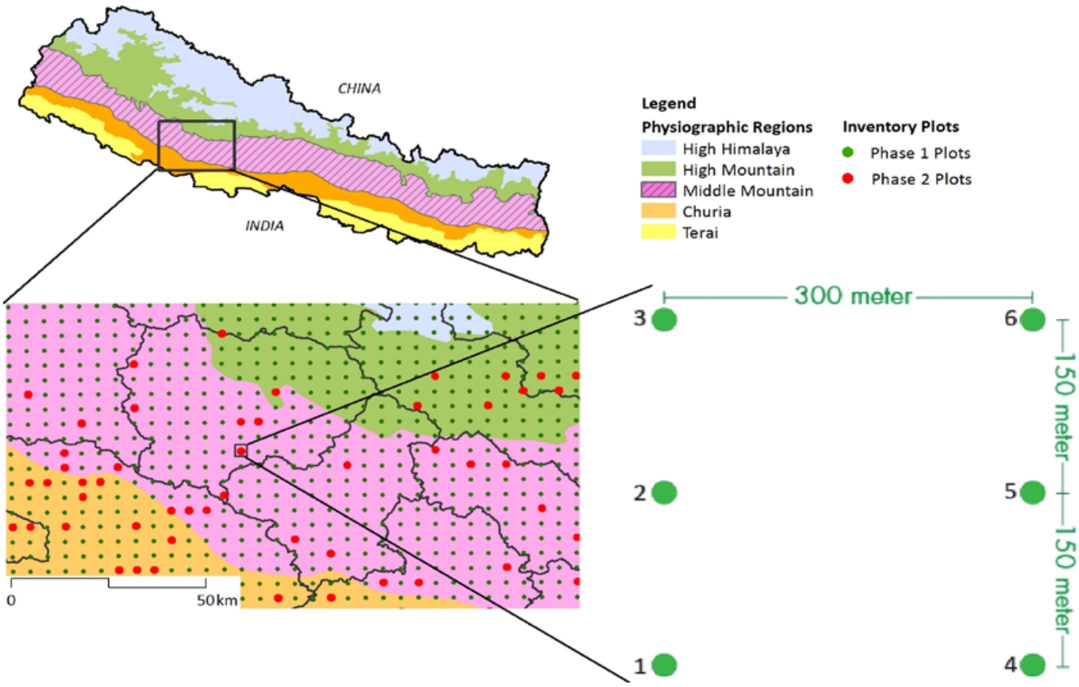


Figure 7:*FRA cluster, sample plot design and layout*

Sample Plot Design

Each sample plot had four concentric circles of different radii, four vegetation sub-plots, four shrubs and seedlings sub-plots, and four soil pits. The plot design for tree measurement is given in the Table 2 below and Figure 8.

Table 2: *Size and area of concentric circular plots of different radii with DBH limits*

S.N.	Plot radius (m)	DBH limit (cm)	Area (m^2)
1	20	≥30.0	**1256.63**
2	15	20.0–29.9	**706.86**
3	8	10.0–19.9	**201.06**
4	4	5.0–9.9	**50.27**

Other sub-plots were established to assess the status of seedlings, saplings, shrubs and herbs. Seedlings, saplings and shrubs were measured in four circular sub-plots, each with a radius of 2 m, located 10 m away from the centre of the plot in each of the four cardinaldirections (north, east, south and west). Species-wise stem counting and mean height estimations were carried out for tree and shrub species having DBH less than 5 cm. Information on non-woody vascular plants was collected from four 1 m^2 plots, each located 5 m away from the centre in the four cardinal directions. Dead and decaying wood was assessed in a circular plot with a radius of 10 m from the plot centre.

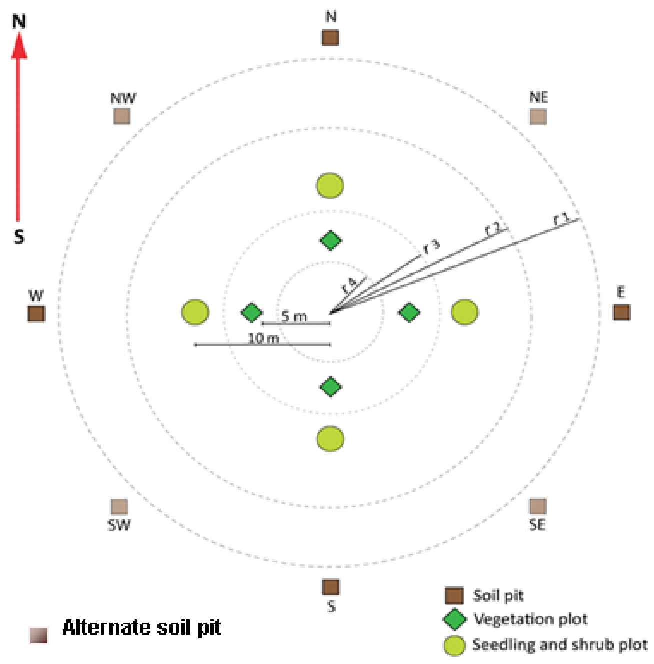


***Figure 8**: Layout of concentric circular sample plot and other sub-plots used*

Fourteen categories of natural and anthropogenic forest disturbances were assessed through field observations of both their occurrence and intensity (high, medium, low) in the 20 m radius plot. The presence of mammals was assessed by using footprints, scat, calls and markings both inside each 20 m plot as well as outside each plot as teams moved from one plot to the next. Four soil pits per forest stand was prepared in order to identity soil texture and to determine soil stoniness. Soil, litter and debris were collected as composite samples by combining the materials collected at all three or four soil pits (see section 3.12). Information related to ethno-botanical uses of different Non Timber Forest Products (NTFPs) was obtained through social surveys conducted in villages near the clusters.

3.5 Tree Resources on Other Wooded Land and Other Land

Information regarding tree resources in OWL and Other Land was obtained by measuring 440 plots (63 OWL and 377 Other Land). They included all plots located in both forest and non-forest strata. The concentric circular plots used for tree assessment were the same as those used in forest plots but no other sub-plots (seedling, sapling, shrubs, herbs and soil) were defined and these were not made permanent.

3.6 Quality Assurance of Forest Inventory Tree Data

About 7% of the total plots of forest plots inventoried were systematically selected and re-measured in order to assess the quality of the initial forest inventory field measurement and provide feedback to the crew members and, in doing so, improve the FRA Nepal Field Manual.

3.7 Tree-Height Modelling

The total height of trees is an important predictor of essential forest parameters such as volume and biomass but its measurement for all trees under forest conditions can be time consuming and impractical. For this reason, height models were prepared for tree species and species groups by using data collected from sample trees (every fifth tree) and additional ones if necessary. Tree heights were calculated by using the predicted heights from the models.

A non-linear mixed-model approach was used to establish the relationships between the DBH and total height of trees by using the "*Lmfor"*package in R Software (Mehtatalo, 2012). As indicated below, different models were developed using those non-linear functions most suitable for different species (Annex 1).

In addition, species with only a few sample trees were grouped according to their morphology, family, genus, and existing height-diameter observations, and models were developed for each of these groups.

A model for predicting tree DBH from stump diameter was also developed so that the volume and biomass of trees that had been felled could be estimated.

3.8 Volume and Biomass Estimation

The volume equations developed by Sharma and Pukkala (1990) and the biomass models prescribed by MPFS (1989) were used to estimate the volume and biomass of standing trees. The air-dried biomass values obtained from these equations were then converted into oven-dried biomass values by using a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012) and a carbon-ratio factor of 0.47 (IPCC, 2006).

Stem volume estimation**:** The following allometric equation (Equation 2) developed by Sharma and Pukkala (1990) was used to estimate stem volume over bark:

Equation 2: *Stem volume*

$$\ln(v) = a + b \ln(d) + c \ln(h)$$

where,

ln = Natural logarithm to the base 2.71828.

V = Volume (dm^3) = exp [a + b×ln(DBH) + c×ln(h)]

d = DBH in cm

h = Total tree height in m

a, b and c are coefficients depending on species

Note: Values were divided by 1,000 to convert them to m^3.

The regression parameters of Equation 2 are presented in Table 3.

Table 3: *Species-specific coefficients used for calculating the volumes of individual trees*

SN	Species	Local name	a	b	c
1	*Acacia catechu*	Khair	-2.3256	1.6476	1.0552
2	*Haldina cordifolia*	Haldu/Karma	-2.5626	1.8598	0.8783
3	*Albizia* spp.	Siris	-2.4284	1.7609	0.9662
4	*Alnus nepalensis*	Utis	-2.7761	1.9006	0.9428
5	*Anogeissus latifolia*	Banjhi	-2.2720	1.7499	0.9174
6	*Bombax ceiba*	Simal	-2.3865	1.7414	1.0063
7	*Toona ciliata*	Tooni	-2.1832	1.8679	0.7569
8	*Dalbergia sissoo*	Sissoo	-2.1959	1.6567	0.9899
9	*Syzygium cumini*	Jamun	-2.5693	1.8816	0.8498
10	*Lagerstroemia parviflora*	Bot dhaiyero	-2.3411	1.7246	0.9702
11	*Magnolia champaca*	Chanp	-2.0152	1.8555	0.7630
12	*Pinus roxburghii*	Khotesalla	-2.9770	1.9235	1.0019
13	*Pinus wallichiana*	Gobre salla	-2.8195	1.7250	1.1623
14	*Quercus* spp.	Khasru	-2.3600	1.9680	0.7469
15	*Schimawallichii*	Chilaune	-2.7385	1.8155	1.0072
16	*Shorea robusta*	Sal	-2.4554	1.9026	0.8352
17	*Terminalia alata*	Asna	-2.4616	1.8497	0.8800
18	Miscellaneous in Terai		-2.3993	1.7836	0.9546
19	Miscellaneous in Hills		-2.3204	1.8507	0.8223

Source: Sharma and Pukkala (1990)

Stem volume without bark (up totop 10 cm and 20 cm) was calculated by using equations developed by Sharma and Pukkala (1990). The volume of individual broken trees was estimated using a taper curve equation developed by Heinonen*et al.* (1996).

Tree-stem biomass estimation: Tree-stem biomass was calculated by using Equation 3 and species-specific wood-density values (Table 4).

Equation 3: *Tree-stem biomass*

Stem biomass = Stem vol. × Density

where,

Vol. = Stem volume in m^3

Density = Air-dried wood density in kg/m^3

Table 4*: Stem-wood density of Middle Mountains trees*

Species	Local name	Air-dried density (kg/m^3)
Acacia catechu	Khair	960
Haldina cordifolia	Haldu/Karma	670
Albizia spp.	Siris	673
Alnus nepalensis	Utis	390
Anogeissus latifolia	Banjhi	880
Bombax ceiba	Simal	368
Castanopsis spp.	Katus	740
Toona ciliata	Tooni	480
Dalbergia sissoo	Sissoo	780
Syzygium cumini	Jamun	770
Lagerstroemia parviflora	Bot dhaiyero	850
Litsea spp.	Kutmiro	610
Magnolia champaca	Chanp	497
Myrica esculanta	Kaphal	750
Pinus roxburghii	Khotesalla	650
Pinus wallichiana	Gobresalla	400
Quercus spp.	Khasru	860
Rhododendron spp.	Gurans	640
Schima wallichii	Chilaune	689
Shorea robusta	Sal	880
Terminalia alata	Asna	950
Miscellaneous in Terai		674
Miscellaneous in Hills		674

Source: Sharma and Pukkala (1990); MPFS (1989)

Biomass estimation of tree-branch and foliage**:** The separate branch-to-stem and foliage-to-stem biomass ratios prescribed by MPFS (1989) were used to estimate branch and foliage biomass from stem biomass (Table 5). Dead trees were not taken into account for this estimate.

Table 5: *Branch-to-stem and foliage-to-stem biomass ratios of various tree species*

Species	Local name	Branch-to-stem			Foliage-to-stem		
		Small	Medium	Big	Small	Medium	Big
Alnus nepalensis	Utis	0.803	1.226	1.510	0.169	0.089	0.060
Castanopsis spp.	Katus	0.398	0.915	1.496	0.053	0.048	0.042
Dalbergia sissoo	Sissoo	0.684	0.684	0.684	0.010	0.010	0.010
Lyonia spp.	Angeri	0.879	0.709	0.670	0.506	0.714	0.850
Myrica esculenta	Kaphal	0.524	0.590	0.605	0.170	0.160	0.155
Pinus roxburghii	Khotesalla	0.189	0.256	0.300	0.101	0.046	0.033
Pinus wallichiana	Gobresalla	0.683	0.488	0.410	0.403	0.238	0.180
Quercus spp.	Khashru	0.747	0.960	1.060	0.229	0.215	0.202
Rhododendron spp.	Gurans	0.544	0.910	1.135	0.277	0.225	0.212
Rhus spp.	Bhalayo	0.601	0.630	0.640	0.143	0.083	0.080
Schima wallichii	Chilaune	0.520	0.186	0.168	0.064	0.035	0.033
Shorea robusta	Sal	0.055	0.341	0.357	0.062	0.067	0.067
Other species	-	0.400	0.400	0.400	0.070	0.050	0.040

Source: Adapted from MPFS, 1989

The total biomass of individual trees was estimated by using Equation 4.

Equation 4: *Total biomass of each individual tree*

Total biomass = Stem biomass + Branch biomass + Foliage biomass

Below-ground biomass:This estimation was calculated by using default value as recommended by IPCC (2006). The value of 0.25 was used, which is the average of five different forest types (primary tropical/sub-tropical moist forest = 0.24, primary tropical/sub-tropical dry forest = 0.27, conifer forest having more than 150 t/ha above-ground biomass = 0.23, other broadleaf forest having 75 t/ha to 150 t/ha above-ground biomass = 0.26, and other broadleaf forest having more than 150 t/ha above-ground biomass = 0.24).The biomass of seedlings and samplings having DBH less than 5cm was not incorporated.

3.9 Reliability of the Results

The mean volume and mean biomassper hectare were estimated by dividing the sum of plot level volume or biomass estimates by the number of sample plots(plot centres). If trees were measured only for a part of the plot (due to inaccessibility of the other part of the plot), the plot level volume or biomass was corrected by using the percentage of the measured plot. Correction was done separately for each of the four Concentric Circular Sample Plots.

The variance of mean volume estimate in forest was estimated by using the variance estimator of a ratio estimator given in equation 5 (Cochran, 1977).

Equation 5:*Variance estimator of a ratio estimator*

$$v(\bar{x}^F) = \frac{1}{(\sum^n m_i)^2} \frac{n}{n-1} \sum^n \left(x_i - \bar{x}^F \cdot m_i\right)^2$$

where,

n=number of clusters with at least one forest plot

m_i=number of forest plots in cluster i

x_i=sum of plot level volumes in cluster i, m^3/ha

$\bar{x}^F$=mean volume in forest.

Standard error of estimates was estimated as the square root of the variance.

For other land cover classes (OWL, OL) the variances were estimated with the same formula but replacing the mean volume in forest by the mean volume, number of forest plots and number of clusters with at least one forest plot by the respective values in the class in question.

In practice, the variance estimator of a ratio estimator produces in many cases estimates of variance that are almost equal to the simple variance of cluster means. However, the ratio estimator should be used when the size of clusters is not equal (Cochran, 1977). In FRA, the size of clusters varied because the number of plots in the land cover class in question varied. The forest types, management regimes, canopy cover, development status, Development Region-wise variables had been calculated by using respective number of plots in the category.

3.10 Forest Disturbances

Fourteen types of disturbances at four levels of intensities were assessed based on 433 sampled plots (each with a 20 m radius).

Forest disturbances were categorised as follows.

No disturbance: No signs of significant disturbance observed

Landslide: Signs of landslide and/or flooding observed

Grazing: Presence of the hoofmarks and dung of animals, broken tops of seedlings and saplings, signs of trampling, disturbed forest litter

Lopping: Cutting of the side branches of trees for fodder

Leaf litter collection: Collection of dead leaves on the forest floor

Bush cutting: Sign of cutting shrubs and bushes.

Forest fire: Sign of forest fire observed caused by natural and human activities

Encroachment: Encroachment in forest for cultivation and plantation

Resin tapping: Tapped trees, ordinarily pines, were identified by cuts made in the boles of trees to enable resin to ooze out

***Lathra* cutting:** Cutting of saplings and poles having DBH <30 cm.

Tree cutting: Cutting of trees >30cm DBH

Insect attack: Plant leaves with signs of insect attacks (e.g. holes, nests, etc.)

Plant parasites: Presence of parasitic plants in trees

Plant disease: Disease caused mainly by fungi (e.g. black rot) or bacteria (e.g. rotting). If a tree was rotting due to resin-tapping the disturbance was recorded as resign-tapping, not as plant disease

Wind, storm, hail: Sign of trees broken and erosion on forest floor caused by wind, storm, hail.

Other human-induced disturbances: Disturbances by humans other than those described above (e.g. removing the bark from the base of a tree, snaring, foot trails, forest roads, etc.)

The intensity levels of the above-mentioned disturbances were classified as below:

Intensity level 0: No significant disturbance.

Intensity level 1: Minor disturbance (little or no effect on trees and regeneration, less than 10% of trees and seedlings affected).

Intensity level 2: Moderate disturbance (tangible effect on trees and regeneration. 10–25% of trees and seedlings affected).

Intensity level 3: Severe disturbance (significant effect on trees and regeneration. more than 25% of trees and seedlings affected)

3.11 Biodiversity Analysis

The lists of flora and fauna species obtained from the field sample plots and social surveys were verified by using various sources (Edwards, 1996; DPR, 2007; Press*et. al.,* 2000, and Bhuju *et* *al.,*2007). Annotated lists were prepared by incorporating both sample plot and social surveys data. The social survey was conducted in focus group discussions with office-bearers of CFs, women, disadvantaged groups, local healers, and NTFPs collectors. Social survey was conducted in each forest cluster (149 meetings).

Detrended correspondence analysis (DCA) with default options in Canoco 5.01 (ter Braak and Smilauer, 2012) was used to identify the compositional gradient length in standard deviation units of plots. Multivariate tests of species composition were carried out by using unimodal technique because there was only presence/absence data (Leps and Smilauer, 2003) and gradient length was very long (11.60), so the Canonical Correspondence Analysis (CCA)was used to show the relationship between species and environmental variables. The significance of the predictors was tested by using Monte Carlo permutation test.

Frequencies of tree species (the proportion of sampling units containing a given tree species) were calculated using Equation 6.

Equation 6: *Tree species frequency*

$$f = \left(\frac{n_i}{N}\right) \times 100$$

Where,

f_i = Frequency of species *i*

n_i = Number of plots on which species *i* occurred and

N = Total number of plots studied

Alpha diversity (α) was calculated using Equation 7.

The Shannon-Weaner diversity index was used to calculate species diversity as shown in Equation 7.

Equation 7: *Shannon-Weaner diversity index*

$$\overline{H} = -\sum_{i=1}^{s}(p_i)(ln\ (p_i)$$

Where,

$\overline{H}$ = Shannon-Weaner index of diversity (for trees and shrubs)

P_i = Proportion of total number of individual of species *I* (n_i/N)

S = Total number of individual species

n_i = Number of individual species *i*, ranging from 1to S.

N = Total number of all species

ln = Natural logarithm

3.12 Forest Soil Assessment

The top 30 cm layer of soil of each forest stand was sampled and assessed in order to determine soil characteristics and soil organic carbon (SOC) stocks. Field work included the collection of litter and woody debris (wood pieces with diameters less than 10 cm, the smallest diameter of the dead wood fraction), preparation of three or four soil pits per forest stand, identification of soil texture, and determining of soil stoniness. Both litter and debris, and soil were collected as composite samples by combining the materials collected at all three or four soil pits (Figure 9).

Organic carbon stock in both the litter and debris fractions were obtained on the basis of the total fresh mass collected from a known area in the field. The dry mass of litter and debris and the SOC content were analysed in the laboratory, then the results calculated per hectare were combined with the characteristics of the forest stand and inventory cluster.

The final SOC value was obtained after correcting the laboratory values by considering the degree of stoniness determined in the field. This correction was needed because no organic carbon is found within stones and laboratory analyses give the organic carbon content only for the fine soil fraction (that fraction with particles less than or equal to 0.5 mm in diameter).

Assessment of Composite Samples of Litter and Woody Debris

Litter and debris fractions were collected from 1 m^2 circular spots located on the surface of each soil pit before it was dug. Litter and woody debris were collected in separate plastic bags, combining the respective fractions collected from all three or four sub-sampling spots in the same bags as composite samples representing the forest stand as a whole. A value of zero was recorded for spots without any litter or debris on the soil surface to ensure that the estimate of average litter or woody debris mass per unit area would be correct.

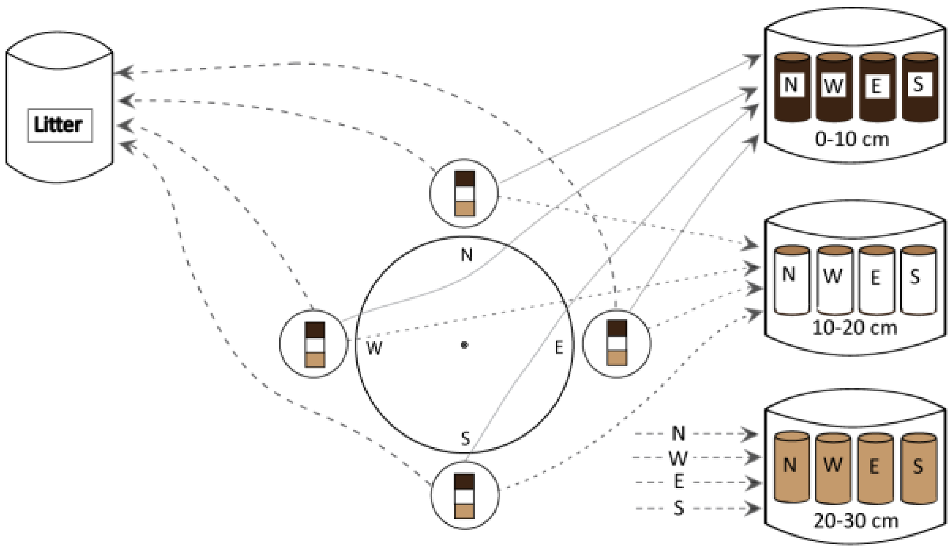


Figure 9*: Collection of composite samples of litter, debris and soil from a plot*

The total fresh mass of both litter and debris was weighed in the field to an accuracy of 1 gram. As the total volume of all 3–4 m^2 (the total of three or four 1 m^2 plots) was very large, small representative sub-samples were set aside so that their dry masses could be determined in the laboratory.

Sampling of Soil

Soil samples were collected from all soil pits. Each pit was dug within a 2 m x 2 m area located 1 m outside of the 20 m plot radius and sized to ensure that the samples would be of undisturbed soil. The samples were collected by using a 100 mm long, slightly conical cylinder corer with a lower diameter of 37 mm (at its cutting edge) and an upper diameter of 40 mm; the volume of each soil sub-sample collected was 107.5 cm^3.

A composite soil sample was collected from each plot; it included soil from each of four soil pits unless the designated pit turned out to be on cropland, a steep slope (>100%), riverbank, or road or in a rocky area or water body. If a cardinal point was inaccessible, the sub-cardinal point (northeast, southeast, southwest, and northwest) clockwise of that point was substituted. In all cases, there were at least three soil-sampling points within each forest stand of each plot, even if there were several stands.

Separate plastic bags were used to collect the composite soil samples for each of three layers: 0–10 cm, 10–20 cm, and 20–30 cm (Figure 9), and the fresh mass of the composite sample was weighed to an accuracy of 1 gram. The bags were transported from the field to the DFRS soil laboratory, where they were stored separately in order to facilitate the assessment of the vertical distribution of SOC across the layers.

Determination of Soil Characteristics

The soil pits were used to determine soil characteristics, including soil texture and stoniness, by observing the soil profiles impressed upon the soil-pit walls (Figure 10) with the help of the FAO's guidelines (FAO, 2006).

***Figure 103**: Soil sample pit*

3.13 Analyses in the Laboratory

Determination of Physical Parameters

The composite samples of soil and sub-samples of litter and woody debris were analysed in the DFRS Soil Laboratory in Babarmahal, Kathmandu. SOC stock was calculated by using the dry soil bulk density (g/cm^3) and the proportion of SOC. The dry bulk-density of the fine soil fraction (<2 mm) was determined from the volumetric composite samples in order to calculate the SOC stock in each of the three 10 cm deep layers collected in the field. Soil is void of organic carbon in any portion of the total volume occupied by coarse fraction particles such as pebbles, gravel, and stones. The volume of any large particles, typically less than 20 mm in diameter that were found in the volumetrically cored samples was eliminated when calculating the bulk density of the fine fraction.

Determination of Soil Organic Carbon

The preparation of the samples and the SOC analysis followed the procedures detailed in the Laboratory Standard Operative Procedures (FRA Nepal, 2011), as summarised below.

The coarse fraction ≥ 2 mm was separated with a 2 mm sieve, and its volume was measured by using water displacement method. This volume was subtracted in order to calculate the bulk density of the fine fraction. The fine fraction that passed through the 2 mm sieve was further homogenised by sieving it again using a 0.5 mm sieve, and the sieved fine fraction alone analysed for OC%.

When soil samples arrived at the laboratory, they were still in moist condition, so they were immediately air-dried in order to stabilise them. They were oven-dried to achieve a constant mass and moisture content. Because of limited supplies of electricity and, in some cases oven capacity, the oven-drying period was shortened from the conventional duration of overnight to, in some cases, a single hour only. The resultant error that may occur in the dry bulk density figures calculated will be reflected in the final SOC results as well, but because the fieldwork was done during the dry season, the degree of error is considered to be low, especially as air-drying was also used.

Walkley-Black wet combustion method with titration was applied in the analysis of the proportion of SOC. Since the method can recover only about 77% of SOC, a correction factor of 1.33 was applied. An Excel application was produced in order to collect, organise, and speed up laboratory calculations. The application also calculated the carbon stocks of litter, woody debris, and the soil fine fraction.

Litter and woody debris were not analysed for the proportion of organic carbon they contain; instead, a carbon content of 50% (Pribyl, 2010) was applied to an estimate of the dry mass / m^2 determined by using the fresh mass of litter and woody debris measured in the field and the dry mass of the sub-samples oven-dried in the laboratory.

Quality Assurance of SOC Analysis

In order to validate the soil carbon analytical methodology used by FRA Nepal, the Institutional Cooperation Instrument Nepal-Project compared the SOC results from Terai soil plots determined by the DFRS Soil Laboratory with the Metla Soil Laboratory in Finland (FRA/DFRS, 2014). The DFRS laboratory used the Walkley-Black wet combustion method and the Metla laboratory used dry combustion LECO CHN analysis. Because dry combustion methods analyse the CO_2 emitted from a sample burned at a high temperature, they may overestimate SOC if a sample contains inorganic carbonates. For this reason, Metla used hydrochloric acid to eliminate the carbonates and washed out the resultant chlorides with water so they would not harm the analyser (Westman *et al*., 2006).

The results of the two laboratories were consistent for low values of SOC% (0–3%), so there was no need for additional correction coefficients or changes in procedure. However, the results were inconsistent for the single high organic carbon value (>3%) found. Comparison with the Metla dry-combustion value suggests that the Walkley-Black method used in DFRS analyses under-estimated the high organic carbon value.

Compilation of SOC Stock Estimates

The SOC stock, measured in g/m^2, in the 30 cm topsoil was calculated by using the following equation:

Equation 8: *SOC stock in 30 cm of topsoil*

$$SOC_{30\ cm},\ g/m^2 = OC_{FF} * BD * 300\ 000 * (1 - Stoniness)$$

Where,

OC_{FF} denotes the proportion (0–1) of organic carbon (OC) in the soil fine fraction (FF),

BD is bulk density of soil, g/cm^3,

300,000 is the coefficient for volume (cm^3) of the 30 cm deep topsoil layer, and

Stoniness denotes the proportion (0–1) of stones per soil volume.

The forest stand-wise SOC% values thus obtained werescaled up to t/ha prior to use for reporting.

Soil stoniness was not observed for each soil pit by the field teams. In fact, based on data recorded on field forms, stoniness was estimated for only 30 clusters out of 130. This is problematic because when calculating SOC stocks, the organic carbon content of the fine fraction has to be corrected by using the proportion of stones in the given profile. Because so much data was missing, SOC% was corrected by using the following three criteria:

1. When the stoniness value was available, it was used to correct the fine fraction SOC % estimate.
2. When there was no stoniness value for a given pit, the value for any other forest stand in the same cluster was used to correct the fine fraction SOC% estimate.
3. If no stoniness values were available from any of the cluster's forest stands, the average stoniness value of all 30 measured clusters was used for the correction.

Estimation of Mean and Standard Errors

The carbon contents of soil, litter and debris were all calculated by using ratio estimates (Cochran, 1977) in order to account for intra-cluster correlations.In other words, more pronounced similarities were expected among nearby clusters than among distant clusters.

4. TECHNICAL CHALLENGES AND LIMITATIONS

4.1 Remote Sensing

Visual Interpretation in Phase-1 Plot Sampling

On-screen visual interpretation as a pre-processing step makes it possible for an interpreter to easily integrate the different characteristics of objects (e.g. surface texture) visible in an image and benefit from direct knowledge of the context. Unlike digital classification methods, such interpretation does not require specialised software though it did face the following challenges:

- Some of the images interpreted in 2010 were partly from 2003–2005, and land cover changes in the intervening years could have caused discrepancies with fieldwork results.
- Google Earth Images might have some local geometrical distortions which can lead to misinterpretation of the boundaries between two land cover types, and visual interpretation may be distorted by human error in classifying land cover.

4.2 Forest Cover Mapping

Remote sensing-based mapping of vegetation and its types is a challenging task to begin with and these challenges are exacerbated by the difficult and varied terrain and climate of Nepal. With a scientific and technically sound approach, appropriate remote sensing materials and the support of reliable and extensive ground samples, multi-source mapping of vegetation/forest can be achieved with a good degree of accuracy and reliability. However, FRA faced several technical limitations and challenges while mapping forest and non-forest areas in Middle Mountains region. The limitations encountered during the mapping process were:

- The forest cover mapping results could not be comparedwith the previous National Forest Inventory (NFI, 1999), which assessed Middle Mountains forests area based on photo point interpretation on aerial photos.
- The fact that image acquisition months (December, February, March and April) varied means that atmospheric conditions differed, thus creating challenges for carrying out atmospheric correction and normalising automated image analysis. It may also have inducedcertain errors in forest cover mapping.
- The classification and analysis of forest cover was complicated by the fact that some deciduous trees, e.g.*Shorea robusta*, *Acacia catechu* and *Anogeissus latifolia* were defoliated during the period of image acquisition(Figure 11), therefore classification and analysis of such forest cover

was challenging. Although, secondary images and maps were used as reference for classification, there still may have been errors.

Figure 11:*Defoliated Acacia catechu forest in Mid-Western Nepal*

- The spatial heterogeneity of forest stands and the fuzziness of their boundaries might have introduced errors into their classification and delineation.
- Mapping of shrub areas was extremely challenging due to the limitations of the images used and the insufficiency of field reference data. In particular, areas visually interpreted and mapped as shrub areas in the high resolution images were mostly found to be patches of regeneration and degraded forests. Ground verification and mapping also indicated that shrub patches were extremely fragmented and small (<0.25 ha).
- Similarly, differentiating OWL (including shrub) was made difficult by the limitations of the images used, so misclassification of OWL to shrub or vice versa cannot be ruled out.
- Young regeneration and recent plantation might have been classified as Other Land because they are not spectrally different from the surrounding land cover.

4.3 Forest Inventory

The methodology was designed to collect nationallevel data on per hectare stem volume and biomass of forestswith 10% accuracy at95% confidencelimit. This is the reason why reliability of other findings (number of stems and volume by species, forest type, quality class; number of seedlings and saplings; NTFPs; biodiversity; soil carbon, etc.) may not be within target accuracy level and they are only indicative values. The confidence levels for sub-populations, such as individual Development Regions and physiographic region, could also be lower (FRA Nepal, 2010).

Sampling errors can be assessed accurately only if there is no bias. Besides bias, other sources of inaccuracies included errors in identifying species, taking field measurements, entering field datain the database, and deriving and calculating mathematical formulae. While converting values from average to total and errors from area estimation might affect total values.

It is extremely difficult to conduct temporal analysis of forest parameters without well-established permanent samples plots and well-documented baseline data. Another problem is that errors in the values being compared may be large in comparison with the changes measured. The data analysis relied on biomass equations developed by Sharma and Pukkala (1990). Also, Sharma and Pukkala did not provide species-specific wood densities for all tree species and offered stem-to-branch and stem-to-foliage biomass ratios for only a few tree species. Besides, the values in the biomass tables were only for air-dried biomass. All of these limitations made it difficult to precisely estimate the above- and below-ground biomass and carbon content in Middle Mountains forests.

4.4 Forest Disturbance

Although standard guidelines were issued for categorisation of forest disturbance, this work still faced some unavoidable limitations. For example:

- Classification of the intensity of impact requires some personal judgement, which may vary between crews; and this judgement could also be influenced by the season of data collection.
- Fire scars were more apparent during the winter dry season than immediately after the monsoon rains.

4.5 Biodiversity Assessment

The main limitation of the biodiversity assessment was the very low sampling intensity (<0.0024%), which suggests that it is likely that sparsely distributed species were missed. The species richness value and index included information about woody plants, climbers, and epiphytes, but the values and indexes for herbaceous plants and other taxa might be erroneous because such species are seasonal. In addition, the biodiversity data was collected as a part of tree level data collection based on sampling design for forest inventory, so the methodology might not be adequatefor assessing entire biodiversity. Further, participatory social method was applied for qualitative information of biodiversity, which depended on the informants' knowledge and skills.

4.6 Soil Organic Carbon Analysis

The presence of stones in the top 30 cm soil layer is significant for estimating the organic carbon stock because the space occupied by stones is void of organic carbon. In the Middle Mountains field work, small number of soil pits were assessed for stoniness. This oversight in ancillary data collection must have led to approximation of stoniness with greater uncertainty. In mountain soils the relative role of SOC in total forest organic carbon stock seems high and stoniness has large variability between sites. Therefore, the uncertainty in SOC estimate is more significant than in more homogenous areas such as Terai. Provided that the distribution of stoniness estimates actually collected represents that of Middle Mountain's top soils, the overall estimate of SOC stock for the whole physiographic region may be reasonably correct, but comparison between smaller spatial units suffers from the use of the average estimate of stoniness obtained from the data representing only a small subset of forest stands.

The organic matter content in Middle Mountains soils is typically higher than that in Terai or Churia. In terms of laboratory analyses using the Walkley-Black method, the organic content approached the upper limit of detection of the analysis. No reference analyses were performed in external laboratories. It is possible that the estimates derived from the analyses of the most carbon rich soil samples somewhat underestimate the SOC content, suggesting that the SOC contents reported here may be slightly conservative, and the soil might actually have a bigger role in the total carbon stock.

4.7 Comparison of Forest under broadly applied Management Regimes

Comparison of forest under different management regimes faced several challenges:

- Whilst there was adequate data to justify comparisons between well represented forest management regimes, the survey was not designed for this specific purpose and sampling in less well represented forest management regimes such as religious forest and leasehold forest was insufficient to provide useful data.
- The classification of management regimes relied on local informants but local people do not always know the boundaries of different forest management regimes, as the boundaries are often unclear.
- Comparisons were based on measured forest parameters at the time of field assessment. This was baseline data and comparisons of trends in forest condition will only be possible after repeated assessment of the permanent sample plots.

5. RESULTS

5.1 Area Statistics

Land Cover in Middle Mountains

According to forest cover mapping, 52.30% (2,253,807ha) of Middle Mountains region is covered by Forest and 1.45% (62,287 ha) by OWL, making a total of 53.75% covered by Forest and OWL together (Table 6).The spatial distribution of the Middle Mountains forests is presented in Figure 12.

Table 6: *Area by landcover class in Middle Mountains*

Landcover class	**Area**	
	(ha)	**(%)**
Forest	2,253,807	52.30
Other Wooded Land (OWL):		
- Tree crown cover (5–10%)	29,308	0.68
- Shrub	32,979	0.77
OWL sub-total	62,287	1.45
Other Land	1,993,302	46.25
Total (Forest + OWL + Other Land)	**4,309,396**[1]	**100.00**

Land Cover of Middle Mountains by Region and District

Far-Western Development Region has the highest proportion of forested land (64%), followed by Mid-Western (54%), Central (51%), Eastern (50%) and Western (46%) Development Regions. By area, it is Eastern Development Region which has the largest forested area (481,314 ha), followed by Central (479,295 ha), Western (440,204 ha), Mid-Western (428,187 ha), and Far-Western (424,807 ha) Development Regions. The largest area of OWL is in Far-Western Development Region, and the largest area of shrub in Mid-Western Development Region. The region- and district-wise distribution of different land cover types are presented in Table 7.

[1]The area of the Middle Mountains physiographic region is 4,306,230 ha (Department of Survey, 2001)

Table 7: *District–wise land cover type in Middle Mountains in 2010 (area in ha)*

Development	District	Forest	Other Land	OWL*	OWL (Shrub)	Total
Eastern	Bhojpur	57,829	72,943	161	11	130,944
	Dhankuta	36,463	52,834	225	11	89,533
	Ilam	62,275	58,253	195	57	120,779
	Jhapa	77	309	1		387
	Khotang	58,753	72,857	109	286	132,004
	Morang	9,270	7,004	43		16,317
	Okhaldhunga	36,073	46,251	220	451	82,994
	Panchthar	61,898	51,140	125		113,163
	Sankhuwasava	43,188	36,784	69	53	80,095
	Solukhumbu	403	339	3		745
	Sunsari	1,402	320	3		1,725
	Taplejung	23,671	14,903	11	6	38,591
	Terhathum	30,849	33,776	176	84	64,885
	Udayapur	59,164	35,521	247	37	94,969
	Total	481,314	483,234	1,588	995	967,131
Central	Bhaktapur	2,459	9,836	15		12,311
	Chitwan	26,282	8,779	154	59	35,273
	Dhading	58,512	70,207	212	844	129,775
	Dolakha	22,486	24,716	72		47,274
	Kathmandu	15,129	26,082	67	83	41,361
	Kavre	72,017	63,906	2,073	702	138,697
	Lalitpur	23,682	14,876	318	216	39,093
	Makwanpur	73,947	29,209	225	683	104,065
	Nuwakot	36,147	56,248	131	1,966	94,492
	Ramechap	43,423	62,927	328	412	107,090
	Rasuwa	658	1,446	5	41	2,150
	Sindhuli	68,450	35,237	711	549	104,946
	Sindhupalchowk	36,104	41,486	522	152	78,264
	Total	479,295	444,955	4,832	5,708	934,791
Western	Arghakhanchi	33,276	43,539	484		77,299
	Baglung	26,584	33,758	195	512	61,048
	Gorkha	34,802	62,441	16	300	97,559
	Gulmi	45,172	64,311	310	811	110,603
	Kaski	33,208	40,601	322	431	74,563
	Lamjung	34,126	32,429	12	228	66,795
	Myagdi	1,364	857	27	8	2,256
	Nawalparasi	24,494	16,292	118	629	41,533
	Palpa	58,733	57,822	398	4,160	121,113
	Parbat	19,733	22,482	127	187	42,529

Development	District	Forest	Other Land	OWL*	OWL (Shrub)	Total
	Syangja	**46,516**	**55,764**	**417**	**1,051**	**103,749**
	Tanahu	**82,196**	**73,576**	**344**	**508**	**156,624**
	Total	**440,204**	**503,872**	**2,768**	**8,825**	**955,669**
Mid-Western	Dailekh	**49,145**	**62,770**	**770**	**299**	**112,983**
	Dang	**37,501**	**19,374**	**58**	**722**	**57,655**
	Jajarkot	**28,853**	**29,036**	**640**		**58,529**
	Pyuthan	**55,258**	**59,838**	**347**		**115,442**
	Rolpa	**71,899**	**57,680**	**731**	**3,746**	**134,057**
	Rukum	**9,087**	**11,533**	**26**	**867**	**21,513**
	Salyan	**92,950**	**58,783**	**428**	**3,257**	**155,418**
	Surkhet	**83,494**	**47,359**	**1,580**	**1,553**	**133,986**
	Total	**428,187**	**346,372**	**4,580**	**10,444**	**789,582**
Far-Western	Achham	**84,341**	**53,277**	**3,013**	**733**	**141,364**
	Baitadi	**85,768**	**55,619**	**4,490**	**1,507**	**147,385**
	Bajhang	**17,595**	**15,375**	**88**	**307**	**33,365**
	Bajura	**205**	**465**	**248**		**918**
	Dadeldhura	**81,376**	**28,729**	**530**	**1,350**	**111,985**
	Darchula	**17,771**	**9,551**	**6,026**	**839**	**34,187**
	Doti	**136,868**	**50,783**	**1,120**	**2,270**	**191,041**
	Kailali	**882**	**1,070**	**24**		**1,976**
	Total	**424,807**	**214,869**	**15,540**	**7,006**	**662,222**
	Grand total	**2,253,807**	**1,993,302**	**29,308**	**32,979**	**4,309,396**

*Crown cover 5–10% of tree species.

Forest CoverInside and Outside Protected Areas

Out of the total 2,253,807 ha of Forest in Middle Mountains, 98.78% falls outside PAs, and 1.22% inside PAs (0.74% in Core Area and 0.48% in Buffer Zone). Each region contains approximately one-fifth of the total Forest, but Central and Far-Western Development Regions have significantly largerForest areas located inside Core Area and Buffer Zone than do the Eastern and Western Development Regions (Table 8).

Table 8: *Forest area inside and outside Protected Areas (ha) in Middle Mountains*

Development region	Inside Protected Areas		Outside Protected Areas	Total area	Percentage
	Buffer Zone	Core Area			
Eastern	**1,281**	**~0**	**480,033**	**481,314**	**21.36**
Central	**1,200**	**10,027**	**468,068**	**479,295**	**21.27**
Western	**~0**	**5,461**	**434,742**	**440,204**	**19.53**
Mid-Western	**~0**	**~0**	**428,187**	**428,187**	**19.00**
Far-Western	**8,384**	**1,180**	**415,242**	**424,807**	**18.85**
Grand total	**10,865**	**16,669**	**2,226,273**	**2,253,807**	**100.00**
Percentage	**0.48**	**0.74**	**98.78**	**100.00**	

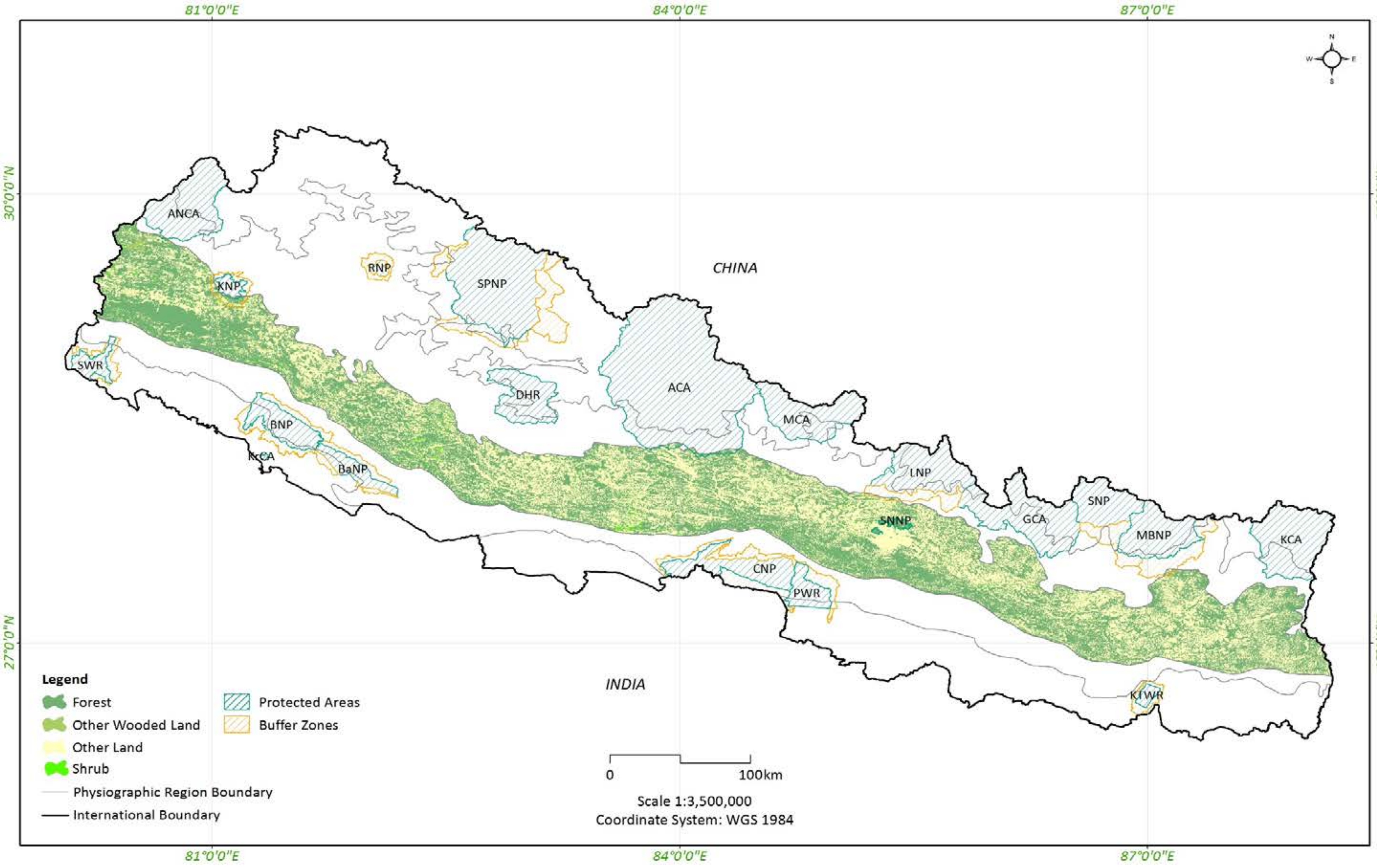


Figure 12:*Middle Mountains Forests of Nepal*

Forest Cover by Slope Class

Outside the protected area and associated Buffer Zone, about 45% of Middle Mountains forests were in the slope class of 60–100%, followed by 35% in 35–60%, 11% in 15–35%, and 2% in 0–15%. About 6% of the forest was on the steepest slopes (>100%) (Table 9, Figure 13). Steep slopes, forest management regimes such as protected areas and associated Buffer Zone, and poor access limit the potential production of saw logs in Middle Mountains forests. While evidence of tree removals was common in all slope classes up to 100%, tree harvesting using humans and draught animals from erosion prone sites should be limited to slopes of less than 35% (FAO, n.d.). Given the FAO recommendation, 296,368 ha (13.29%) of Middle Mountains forests can be regarded as production forests in terms of timber production.

Table 92: *Area of Middle Mountains forests (Outside of PA and BZ) by slope class*

Slope class (%)	Slope class (º)	Area (ha)	Percentage
< 15%	< 8.5	**47,502**	**2.13%**
15-35%	8.5-19.0	**248,359**	**11.16%**
35-60%	19.0-31.0	**782,930**	**35.17%**
60-100%	31.0-45.0	**1,007,626**	**45.26%**
≥ 100%	> 45.0	**139,856**	**6.28%**
Total		**2,26,273**	

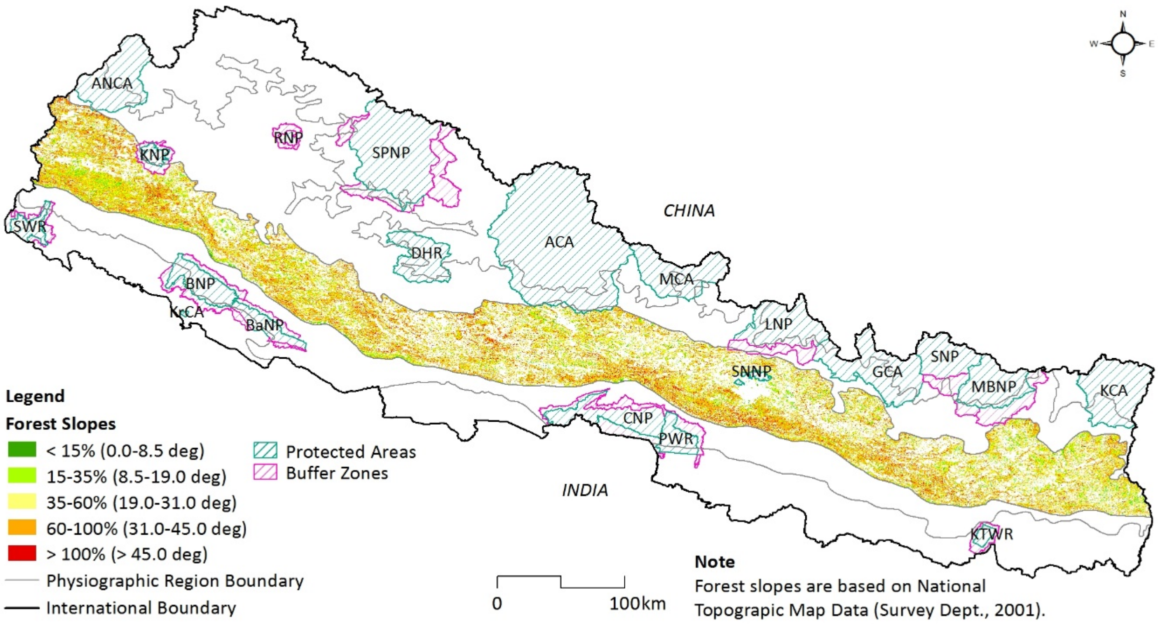


Figure 13: Distribution of slope class in Middle Mountains region

5.2 Forest Patch Size

The average size of forest patches in MiddleMountains (outside of PAs and Buffer Zone) was 59.41 ha. About 58.31% of forest patches were less than 2 ha and 28.25% are just 2–10 ha. Only 13.43% of the forest patches are over 10 ha, with 4.92% between 10–20 ha, 3.91% between 20–50 ha, 1.73% between 50–100 ha, 1.93% between 100–500 ha, 0.26% between 500–1,000 ha, and 0.68% above 1,000 ha (Figure 16).

The largest average patch size is reported fromFar-Western Region (114 ha) followed by Mid-Western (64 ha), Central (56 ha), Eastern (52 ha), and Western (46 ha) Regions.The total area occupied by the 21,850 patches with less than 2 haarea is 21,358 ha which is 1.17% of the total forest in Middle Mountains. In contrast, the three patches over 50,000 ha cover 235,782 ha i.e. 10.59% of the total. The forest patches sized 2–50 ha (N=13,895), 50–100 ha (N=1,472), 100–10,000 ha (N=198) and 10,000–50,000 ha (N=52) cover 5.26%, 12.01%, 28.69%, and 42.50% of the total forest area, respectively (Figure 14).

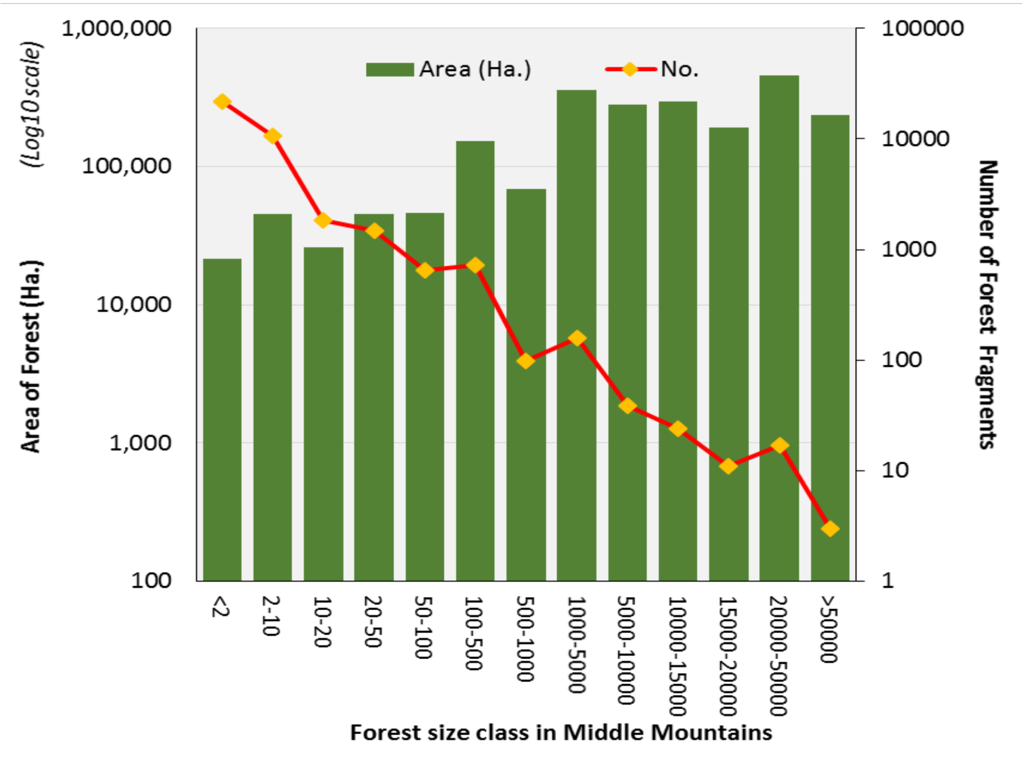


Figure 14: *Forest patchsize of Middle Mountains*

5.3 Accuracy Assessment

The results of Middle Mountains forest cover mapping were compared with 344 independent ground samples, 190 of which were inventory plots and 154 additional purposively observed sample plots in the field. These additional purposively selected sample plots were used to supplement the limited number of OWL and shrub plots in the inventory so that maps could be updated and verified. The land cover classes (Forest, OWL and Other Land) observed in the field were compared with the classified land cover classes (Forest, OWL and Other Land), revealing an overall accuracy of 72.97%, a Cohen's *Kappa* (κ) of 0.62, and a*Kappa* standard error of 0.03 (Table 10).

Table 10: *Error matrix for forest cover map using independent ground verification samples*

Classified Class	Land cover class (ground truth)				User's accuracy	Error of commission
	Forest	**OWL**	**Other Land**	**Total**		
Forest	**95**	**32**	**4**	**131**	**72.52%**	**27.48%**
OWL	**2**	**121**	**0**	**123**	**98.37%**	**1.63%**
Other Land	**5**	**50**	**35**	**90**	**38.89%**	**61.11%**
Total	**102**	**203**	**39**	**344**		
Producer's accuracy	**93.14%**	**59.61%**	**89.74%**			
Error of omission	**6.86%**	**40.39%**	**10.26%**			
Overall accuracy	**72.97%**					

Cohen's Kappa = 0.62. Kappa Standard Error = 0.03

The producer's accuracy for Forest, OWL and Other Land was 93%, 60% and 90%, respectively. An accuracy assessment of shrub classification was excluded for three reasons: the number of sample plots was insufficient for conducting an unbiased accuracy assessment, shrubs were classified using ground observation plots, and the classification of shrubs was challenging given the nature of the remote-sensing material used and the limited ground observation data.

5.4 Forest Inventory

Number of Stems

Number of Stems (DBH ≥5 cm)

InMiddle Mountains, the total number of stems with DBH ≥5 cm was 2,345.72 million of which 1,963.76 million (871.31/ha)was in Forest, 8.37 million (134.45/ha) in OWL and 373.59 million (187.42/ha)in Other Land (Table 11).

Table 113: *Number of stems by land cover class*

Land cover class	No. of plots	No. of stems/ha	Total stems (million)
Forest	433	871.31	1,963.76
OWL	63	134.45	8.37
Other Land	377	187.42	373.59

In Middle Mountains forests, dominant trees comprised the greatest number of stems per hectare (310), followed by co-dominant (238) and intermediate (176). There were about 20 standing dead trees per hectare.About five trees were estimated to have been removed annually (Table 12).

Table 12: *Number of stems per hectare according to tree status*

Tree category	Tree status	No. of stems/ha
Live trees	Dominant	310.47
	Co-dominant	237.62
	Intermediate	175.73
	Suppressed	63.40
	Understory	18.15
	Broken	65.95
Sub-total		**871.31**
Standing dead trees	Dead usable*	16.92
	Dead unusable	3.07
Sub-total		**19.99**
Removal		24.01**
Dead wood		Not Applicable

**Tree stems that can be used at least for firewood*

** A *five-year estimate*

In terms of the number of stems (≥5 cm DBH) per hectare, *Shorea robusta* was the dominant species (155.46/ha), followed by *Rhododendron* spp. (94.02/ha). The average weighted DBH of *Quercus* spp.was the largest (49.18 cm), followed by *Terminalia alata* (42.12 cm). The average weighted height of *Pinus roxburghii* was the greatest (22.02 m), followed by *Pinus wallichiana*(19.04 m) (Table 13).

***Table 13**: Characteristics of common tree species in forests*

Tree species	**No. of stem/ha**	**Weighted[1]**	
		DBH (cm)	**Height**
Shorea robusta	155.46	28.36	16.00
Rhododendron spp.	94.02	26.59	8.75
Quercus spp.	77.97	49.18	15.04
Schima wallichii	68.04	28.39	13.28
Pinus roxburghii	47.19	39.49	22.02
Lyonia spp.	45.05	21.79	8.56
Castanopsis spp.	38.88	30.90	12.72
Alnus spp.	25.84	37.67	18.69
Pinus wallichiana	15.62	29.28	19.04
Lagerstroemia parviflora	15.60	23.00	12.80
Terminalia alata	11.00	42.12	19.61
Acacia catechu	4.05	20.88	12.88
Haldina cordifolia	2.31	39.24	16.53
Other species	270.28	32.00	12.77
Total/Average	**871.31**	**33.35**	**14.80**

In terms of forest types, *Quercus* forests had the greatest number of stems (1,685/ha), followed by Upper Mixed Hardwood forests (1,294/ha) (Table 14).

[1]Weighted on the basis of Basal Area per hectare

Table 14: *Number of stems by forest type*

Forest type	No. of plots	No. of stem/ha
Quercus spp.	21	1,684.91
Upper Mixed Hardwood	42	1,294.04
Shorea robusta	63	1,077.51
Lower Mixed Hardwood	154	852.16
Pinus wallichiana	9	776.22
Khair-Sissoo / Sissoo-Khair	4	685.53
Terai Mixed Hardwood	72	666.51
Pinus roxburghii	68	451.63
Total/Average	**433**	**871.31**

According to DBH class, there were 11 mature stems (≥50 cm), 39 stems with30–50 cm, 81 stems with 20–30 cm, 298 stems with 10–20 cm and 442 stems with 5–10 cm. Table 15 presents number of stems per hectare by major tree species.

Table 15: *Number of stems/hain forests by species and DBH class*

Tree species	DBH class (cm)					Total
	5–10	10–20	20–30	30–50	>50	
Shorea robusta	74.46	58.27	14.19	7.23	1.32	155.46
Rhododendron spp.	48.70	35.03	6.53	3.11	0.64	94.02
Quercus spp.	36.30	30.21	6.96	2.79	1.71	77.97
Schima wallichii	27.11	28.37	7.91	4.03	0.62	68.04
Pinus roxburghii	13.32	16.25	8.37	6.65	2.59	47.19
Lyonia spp.	25.27	16.08	2.74	0.83	0.13	45.05
Castanopsis spp.	16.08	16.12	4.35	1.98	0.35	38.88
Alnus spp.	11.95	8.16	3.82	1.53	0.39	25.84
Pinus wallichiana	5.05	4.94	3.95	1.49	0.18	15.62
Lagerstroemia parviflora	7.81	5.63	1.50	0.62	0.04	15.60
Terminalia alata	5.97	2.64	0.78	1.18	0.42	11.00
Acacia catechu	1.38	2.07	0.59	0.00	0.02	4.05
Haldina cordifolia	0.46	1.03	0.39	0.31	0.11	2.31
Other species	168.16	73.40	18.88	7.57	2.27	270.28
Total	**442.02**	**298.20**	**80.98**	**39.32**	**10.79**	**871.31**

In terms of species and quality, the average number of stems per hectare comprised 150.26 high-quality sound trees (quality class 1), 224.91 sound trees (quality class 2), and 496.14 cull trees (quality class 3). *Shorea robusta* had the greatest number of stems per hectare in quality classes 1 and 2. In quality class 3*, Rhododendron* spp. had the greatest number of stems per hectare (Table 16).

Table 16: *Number of stems inforests by species and quality class*

Tree species	Number of stems/ha			Total	%
	Class 1	Class 2	Class 3		
Shorea robusta	49.23	44.42	61.81	155.46	17.84
Rhododendron spp.	2.13	16.36	75.53	94.02	10.79
Quercus spp.	7.28	28.83	41.85	77.97	8.95
Schima wallichii	9.58	18.68	39.78	68.04	7.81
Pinus roxburghii	28.31	12.86	6.01	47.19	5.42
Lyonia spp.	1.12	8.27	35.66	45.05	5.17
Castanopsis spp.	6.22	11.93	20.74	38.88	4.46
Alnus spp.	9.37	12.80	3.67	25.84	2.97
Pinus wallichiana	12.42	3.20	0.00	15.62	1.79
Lagerstroemia parviflora	1.52	5.36	8.72	15.60	1.79
Terminalia alata	2.99	2.79	5.22	11.00	1.26
Acacia catechu	2.12	1.44	0.49	4.05	0.47
Haldina cordifolia	0.48	1.02	0.81	2.31	0.26
Other species	17.51	56.93	195.85	270.28	31.02
Total	**150.26**	**224.91**	**496.14**	**871.31**	**100.00**

Number of stems (DBH <5 cm)

Regarding regeneration in Middle Mountains forests, an average of 7,171 seedlings (height <1.3m) and 1,167 saplings (height >1.3m and DBH <5cm) per hectare were estimated. *Shorea robusta* was the most numerousin both seedlings (2,866/ha) and saplings (236/ha) (Table 17).

Table 17:*Species-wise regeneration status*

Tree species	Seedlings (No./ha)	Saplings (No./ha)	Total (No./ha)
Shorea robusta	2,866	236	3,102
Castanopsis spp.	291	94	385
Quercus spp.	265	29	294
Schima wallichhi	190	54	244
Mallotus spp.	154	42	196
Rhododendron spp.	136	49	185
Lagerstroemia parviflora	130	29	159
Terminalia alata	71	6	77
Pinus roxburghii	62	6	68
Pinus wallichiana	9	1	10
Other species	2,997	620	3,617
Total	**7,171**	**1,167**	**8,338**

Shorea robusta was the most numerous in both sapling and seedling stages in *Shorea robusta* and TMH forest types while *Quercus* spp. was the most numerousin *Quercus* forest. In KS/SK forests, *Mallotus* spp*. was* the most numerousinsapling (99/ha*)* and seedling (199/ha) stages. Similarly, in UMH forest, *Rhododendron* spp*.* was the most numerous insapling (185/ha*)* and seedling (602/ha) stage. In LMH forests, *Castanopsis* spp. (164/ha) was the most numerousin sapling stage and *Shorea robusta* (619/ha) in seedling stage. In *Pinus roxburghii* forests, *Mallotus* spp. (53/ha) had the highest number in saplingstage while *Shorea robusta* (398/ha)was the most numerousin the seedling stage. In *Pinus wallichiana* forests, *Quercus* spp. (133/ha) had the highest number of seedlings(Table 18).

Table 18: Species composition of regeneration in different forest types

Forest Type	KS/SK		LMH		Pr		Pw		Q		S		TMH		UMH	
Species	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**
Castanopsis spp.	0	0	164	437	0	99	0	44	0	114	63	357	160	370	0	0
Lagerstroemia parviflora	0	0	5	39	9	61	0	0	0	180	38	174	69	122	90	535
Mallotus spp.	99	199	12	74	53	99	0	0	0	0	57	338	122	370	0	0
Pinus roxburghii	0	0	5	10	20	348	0	0	19	47	0	6	0	0	0	9
Pinus wallichiana	0	0	0	0	3	12	0	0	0	66	0	0	0	0	9	43
Quercus spp.	0	0	25	101	18	395	0	133	218	2,217	3	0	0	3	71	583
Rhododendron spp.	0	0	61	120	3	56	0	44	180	436	0	0	3	25	185	602
Schima wallichii	0	0	115	315	9	94	0	0	0	38	44	262	33	138	0	0
Shorea robusta	0	0	70	619	6	398	0	0	0	0	1178	13,547	235	3,680	0	0
Terminalia alata	0	0	4	61	0	61	0	0	0	0	13	174	19	88	0	0
Other species	995	2,934	796	3,226	208	2,525	1835	3,493	502	2700	515	2886	503	2,683	763	3,676
Total/Average	**1,094**	**3,133**	**1,257**	**5,002**	**329**	**4,148**	**1,835**	**3,714**	**919**	**5,798**	**1,911**	**17,744**	**1,144**	**7,479**	**1,118**	**5,448**

Note: KS/SK = *Khair-Sissoo /Sissoo-Khair*; LMH = Lower Mixed Hardwood, Pr = *Pinus roxburghii*; Pw = *Pinus wallichiana*; Q = *Quercus*, S = *Shorea robusta,* TMH= Terai Mixed Hardwood, UMH = Upper Mixed Hardwood

Regeneration was the highest in *Shorea robusta* forests, followed by TMH, Quercus, UMH and LMH. In contrast, regeneration in *Pinus roxburghii* forests was the lowest. The number of seedlings was the greatest in the forests with higher crown cover. In terms of development status, the greatest number of saplings and seedlings werefound in forest stands that were in the seedling and sapling development stages (Table 19).

Table 4: *Regeneration status by forest type, crown cover and development status*

Forest type	**No. of plots**	**Seedlings /ha**	**Saplings /ha**	**Total**
Khair-Sissoo / Sissoo-Khair	4	3,133	1,094	4,227
Lower Mixed Hardwood	154	5,001	1,256	6,257
Pinus roxburghii	68	4,149	328	4,477
Pinus wallichiana	9	3,714	1,835	5,549
Quercus spp.	21	5,798	919	6,717
Shorea robusta	63	17,744	1,910	19,654
Terai Mixed Hardwood	72	7,480	1,144	8,624
Upper Mixed Hardwood	42	5,447	1,118	6,565
Total/Average	**433**	**7,171**	**1,167**	**8,338**
Crown cover				
<40%	67	4,885	508	5,393
40–69%	198	5,111	1,111	6,222
>70%	168	10,511	1,497	12,008
Total/Average	**433**	**7,171**	**1,167**	**8,338**
Development status				
Seedling and sapling stand (<12.5 cm DBH)	26	7,981	1,553	9,534
Pole-timber stand (12.5–25.0 cm DBH)	187	6,822	1,137	7,959
Small saw-timber stand (25.0–50.0 cm DBH)	150	7,256	1,153	8,409
Large saw-timber stand (>50.0 cm DBH)	70	7,622	1,137	8,759
Total/Average	**433**	**7,171**	**1,167**	**8,338**

Seedling regeneration inMiddle Mountains forests was highest in Western Development Region, followed by Central and Mid-Western Development regions.Sapling regeneration was highest inCentral Development Region, followed by Western and Eastern Development Regions. Far-Western Development Region had the least number of seedlings and saplings per hectare (Table 20).

Table 20: *Status of regeneration of forests in different Development Regions*

Development Region	No. of plots	Seedlings/ha	Saplings/ha
Far-Western	67	2,764	529
Mid-Western	85	5,018	910
Western	107	14,158	1,422
Central	93	7,254	1,739
Eastern	81	3,750	973
Total/Average	**433**	**7,171**	**1,167**

Basal Area

The basal area of stems (≥5cm DBH) was 18.40 m^2/ha inForest, 2.33 m^2/ha in OWL, and 4.12 m^2/ha in Other Land (Table 21).

Table 21: *Basal area per ha by land cover class*

Land cover class	No. of plots	Basal area
Forest	433	18.40
OWL	63	2.33
Other Land	377	4.12

The basal area of live treeswas 18.40 m^2/ha, about two-thirds of which was made up by dominant trees. The basal areaof standing dead trees was 0.50 m^2/ha (Table 22).

Table 22: *Basal area by tree status*

Tree category	Tree status	Basal area (≥5 cm DBH), m^2/ha
Live trees	Dominant	11.18
	Co-dominant	4.02
	Intermediate	1.77
	Suppressed	0.46
	Understory	0.10
	Broken	0.88
Sub-total		**18.40**
Standing dead trees	Dead usable*	0.44
	Dead unusable	0.06
Sub-total		**0.50**
Removal		0.36**
Dead wood		Not Applicable

**Tree stems that can be used at least for firewood*

*** A five years estimate*

By forest type, Upper Mixed Hardwood had the greatest basal area (33.39 m^2/ha) followed by *Quercus* forests (25.65 m^2/ha). KS/SK forests had the least basal area (8.53 m^2/ha) (Table 23).

Table 23: *Basal area in forests by forest type*

Forest type	No. of plots	Basal area (m^2/ha)
Upper Mixed Hardwood	42	33.39
Quercus spp.	21	25.65
Shorea robusta	63	21.98
Pinus wallichiana	9	19.92
Lower Mixed Hardwood	154	16.21
Pinus roxburghii	68	14.23
Terai Mixed Hardwood	72	13.40
Khair-sissoo / Sissoo-Khair	4	8.53
Total/Average	433	18.40

In terms of species, *Shorea robusta* had the largest basal area, approximately 17% of the total, followed by *Quercus* spp. *and Pinus roxburghii*, with approximately 12% in each. Table 24 presents basal area of different species in different DBH classes.

Table 24: *Basal areas (m^2/ha) in forests by species and DBH class*

Tree species	DBH Class (cm)					Total
	5–10	**10–20**	**20–30**	**30–50**	**≥50**	
Shorea robusta	0.31	0.94	0.66	0.80	0.38	3.09
Pinus roxburghii	0.06	0.29	0.39	0.78	0.69	2.22
Quercus spp.	0.16	0.48	0.32	0.33	0.85	2.15
Rhododendron spp.	0.22	0.54	0.30	0.33	0.19	1.59
Schima wallichii	0.12	0.48	0.37	0.43	0.18	1.57
Castanopsis spp.	0.07	0.26	0.20	0.22	0.12	0.87
Alnus spp.	0.05	0.14	0.17	0.16	0.15	0.68
Lyonia spp.	0.11	0.24	0.13	0.09	0.03	0.60
Pinus wallichiana	0.02	0.09	0.19	0.16	0.04	0.50
Terminalia alata	0.03	0.05	0.04	0.14	0.13	0.38
Lagerstroemia parviflora	0.03	0.10	0.07	0.06	0.01	0.27
Haldina cordifolia	0.00	0.02	0.02	0.04	0.03	0.10
Acacia catechu	0.01	0.03	0.02	0.00	0.01	0.06
Other species	0.69	1.11	0.86	0.81	0.84	4.31
Total	**1.87**	**4.78**	**3.74**	**4.36**	**3.66**	**18.40**

Volume

In Middle Mountains, the total stem volume (DBH ≥5 cm) was 343.36 million $m^3$of which295.33 million m^3 (131.03m^3/ha) was in Forest, 0.75 million m^3 (12.00m^3/ha) in OWL and 47.29 million m^3 (23.72 m^3/ha) in Other Land (Table 25). The standard error of the mean stem volume was6.29%in Forest.

Table 25: *Stem volume per ha by land cover class*

Land cover class	No. of plots	Stem vol.≥5 cm DBH (m^3/ha)	Standard error of mean stem volume (%)
Forest	433	131.03	6.29
OWL	63	12.00	27.17
Other Land	377	23.72	9.04

The total stem volume of the live trees in Middle Mountains forests was 131.03 m^3/ha.The total stem volumes of standing dead trees and dead wood were 2.52 m^3/ha and 6.81 m^3/ha, respectively (Table 26). The stem volume of removed trees was estimated to be 0.51 m^3/ha/year.

***Table 26**: Stem volume per hectare by tree status*

Tree category	Tree status	Tree stem vol. (m^3/ha)
Live trees	Dominant	91.75
	Co-dominant	24.33
	Intermediate	8.88
	Suppressed	2.15
	Understory	0.45
	Broken	3.46
Sub-total		**131.03**
Standing dead trees	Dead usable*	2.28
	Dead unusable	0.24
Sub-total		**2.52**
Removal		2.54**
Dead wood		6.81

**Tree stems that can be used at least for firewood*

** A five-year estimate

By forest type, Upper Mixed Hardwood forest had the greatest stem volume (219.23 m^3/ha), followed by *Pinus wallichiana* forests (183.73 m^3/ha). KS/SK forest had the least stem volume (54.43 m^3/ha) (Table 27).

***Table 27**: Stem volume by forest type*

Forest type	No. of plots	Stem
Upper Mixed Hardwood	42	219.23
Pinus wallichiana	9	183.73
Shorea robusta	63	167.98
Pinus roxburghii	68	139.58
Quercus spp.	21	139.89
Lower Mixed Hardwood	154	106.23
Terai Mixed Hardwood	72	87.34
Khair-Sissoo / Sissoo-Khair	4	54.43
Total/Average	**433**	**131.03**

In terms of DBH classes, the stem volumewas 6.77 m^3/ha with 5–10 cm, 25.29 m^3/ha with 10–20cm, 25.47 m^3/ha with 20–30 cm, 36.38 m^3/ha with 30–50 cm, and 37.12 m^3/ha with ≥50 cm. *Shorea robusta* had the highest stem volume, 18.38% of the total, followed by *Pinus roxburghii* with 18.22% and *Quercus* spp. with 12.82% (Table 28).

Table 28: *Stem volumes (m^3/ha) by species and DBH classes*

Tree species	DBH Classes (cm)					Total	%
	5–10	**10–20**	**20–30**	**30–50**	**≥50**		
Shorea robusta	1.29	6.18	5.34	7.47	3.80	24.08	18.38
Pinus roxburghii	0.17	1.51	3.08	8.78	10.35	23.88	18.23
Quercus spp.	0.52	2.57	2.20	2.70	8.81	16.80	12.82
Schima wallichii	0.40	2.40	2.17	2.79	1.36	9.11	6.96
Rhododendron spp.	0.73	2.30	1.43	1.77	0.98	7.21	5.50
Alnus spp.	0.27	1.06	1.47	1.57	1.59	5.96	4.55
Castanopsis spp.	0.27	1.37	1.20	1.41	0.91	5.16	3.94
Pinus wallichiana	0.08	0.65	1.77	1.72	0.45	4.66	3.56
Terminalia alata	0.07	0.28	0.28	1.25	1.27	3.16	2.41
Lyonia spp.	0.38	1.03	0.63	0.52	0.19	2.74	2.09
Lagerstroemia parviflora	0.14	0.51	0.42	0.47	0.07	1.60	1.22
Haldina cordifolia	0.00	0.06	0.09	0.29	0.25	0.69	0.52
Acacia catechu	0.03	0.19	0.17	0.00	0.03	0.41	0.32
Other species	2.41	5.18	5.24	5.65	7.07	25.55	19.50
Total	**6.77**	**25.29**	**25.47**	**36.38**	**37.12**	**131.03**	**100.00**

In terms of quality class, the total stem volume of high-quality sound trees (quality class 1) was 70.26 m^3/ha. *Shorea robusta* comprised the major proportion (24.08 m^3/ha, or 18.38%), followed by *Pinus roxburghii* (23.88 m^3/ha, or 18.22%) (Table 29).

Table 29: *Stem volumes by species and quality class (m^3/ha)*

Tree species	Stem volume (m^3/ha)			Total	%
	Class 1	Class 2	Class 3		
Shorea robusta	15.03	5.50	3.55	24.08	18.38
Pinus roxburghii	21.63	1.90	0.36	23.88	18.23
Quercus spp.	7.86	5.19	3.76	16.80	12.82
Schima wallichii	2.70	2.91	3.50	9.11	6.96
Rhododendron spp.	0.45	1.63	5.14	7.21	5.50
Alnus spp.	4.18	1.45	0.33	5.96	4.55
Castanopsis spp.	1.20	1.94	2.02	5.16	3.94
Pinus wallichiana	4.44	0.23	0.00	4.66	3.56
Terminalia alata	2.49	0.39	0.28	3.16	2.41
Lyonia spp.	0.10	0.61	2.03	2.74	2.09
Lagerstroemia parviflora	0.61	0.56	0.43	1.60	1.22
Haldina cordifolia	0.48	0.12	0.09	0.69	0.52
Acacia catechu	0.27	0.09	0.05	0.41	0.32
Other species	8.85	7.12	9.58	25.55	19.50
Total	**70.29**	**29.62**	**31.12**	**131.03**	**100.00**

The largest proportion of the total stem volume was comprised by high-quality sound trees (Table 30).

Table 30: *Stem volume, basal area, number of stems by quality class*

Quality class	Stems	Basal area	Stem vol.
	(no./ha)	(m^2/ha)	(m^3/ha)
High-quality sound tree	150.26	7.53	70.29
Sound tree	224.91	4.55	29.62
Cull tree	496.14	6.32	31.12
Total	**871.31**	**18.40**	**131.03**

In Middle Mountains forests, the proportion of small trees was higher than that of large ones (Figure 15).

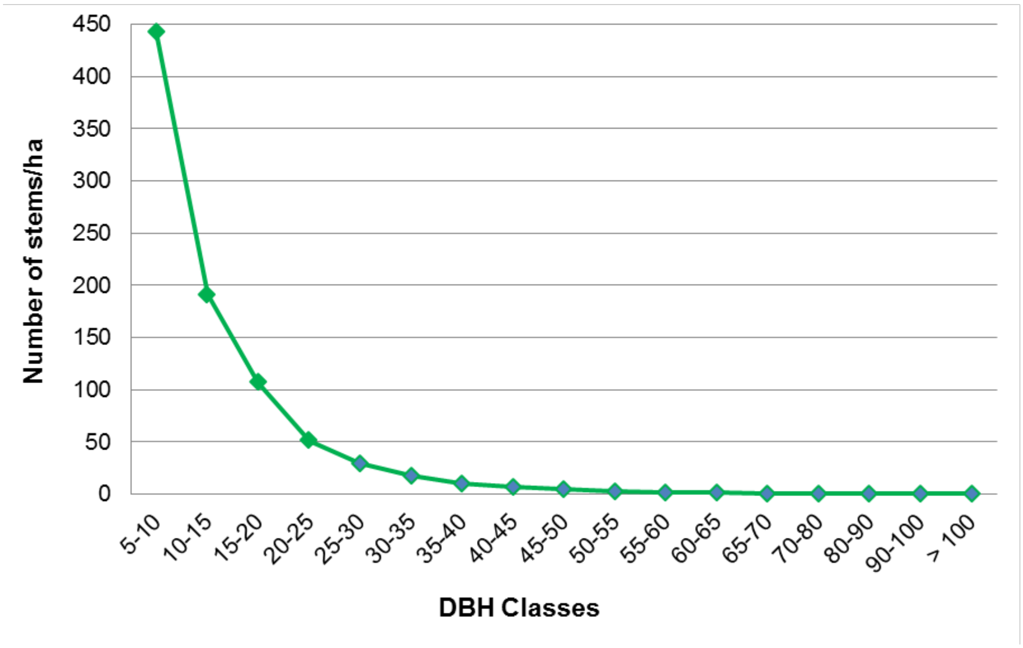


Figure 15: *Number of stems by DBH class*

High-quality sound trees (quality 1) comprised the largest proportion of stem volume in the DBH class >50 cm, followed by 30–50 cm. (Figure 16).

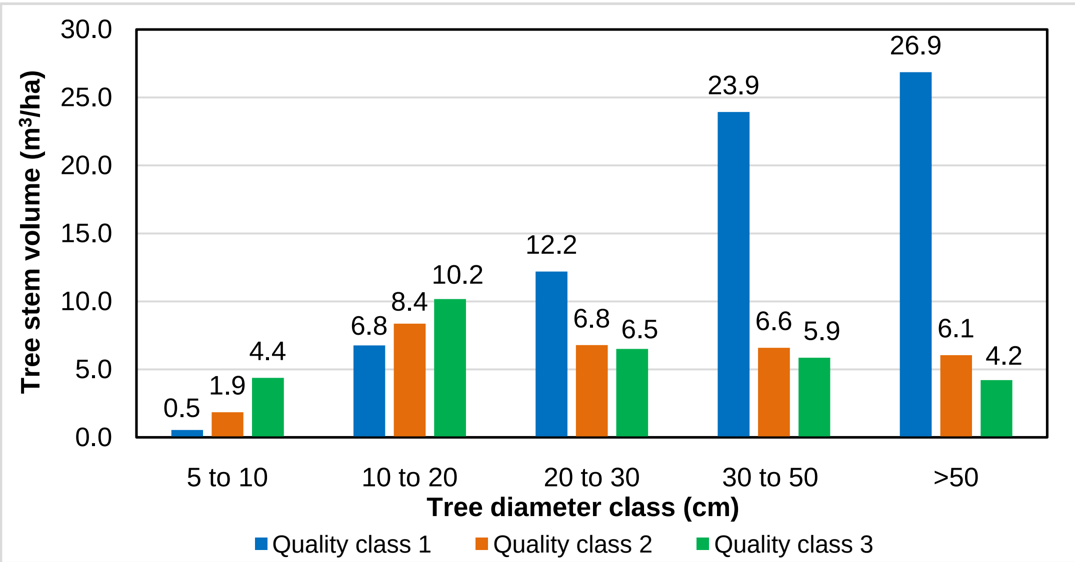


Figure 16: *Distribution of stem volume by quality class and tree size*

Biomass

In Middle Mountains, the total air-dried biomass of live trees with a DBH ≥5 cm was387.96 million tonnesof which 340.05 million tonnes (150.88t/ha) was in Forest, 0.79 million tonnes(12.62t/ha) in OWL and 47.13 million tonnes (23.64t/ha)in Other Land (Table 31).

Table 31: *Tree component wise biomass per ha by land cover class*

Land cover class	No. of plots	Tree component	Air-dried biomass (≥5 cm DBH) (t/ha)
Forest	433	Stem	94.10
		Branch	46.43
		Foliage	10.34
OWL	63	Stem	8.30
		Branch	3.72
		Foliage	0.61
Other Land	377	Stem	15.51
		Branch	7.10
		Foliage	1.03

For Forest, the above-ground air-dried biomass of live trees was 150.88 t/ha and the below-ground biomass was37.72 t/ha. The above-ground biomass and below-ground biomass of dead standing trees were 1.86 t/ha and 0.46t/ha, respectively. The biomass of dead wood was 4.59 t/ha. In total, air-dried biomass of tree component including dead woodin forests was 195.51 t/ha whose corresponding oven-dried biomass was 177.74 t/ha (Table 32).

Table 32: *Above- and below-ground biomass/hain forests (≥5cm DBH)*

I. Live trees	Biomass Components	Air-dried biomass(t) (t/ha)
	Stem	94.10
Above-ground	Branch	46.43
	Foliage	10.34
Below-ground biomass		37.72
II. Dead trees		
	Stem	1.86
Above-ground	Branch	0.00
	Foliage	0.00
Below-ground biomass		0.46
III. Dead wood		
Above-ground	Stem	4.59
Total above-ground biomass (including dead wood)		157.33
Total below-ground biomass		38.18
Total biomass		195.51
Total oven-dried biomass		177.74

By forest type, Upper Mixed Hardwoodforests had the greatest live tree biomass of trees having at least 5 cm DBH (310.35 t/ha), followed by *Quercus* forests (231.12 t/ha). KS/SK forests had the least total biomass (70.55 t/ha) (Table 33).

Table 33: *Total above-groundbiomass in forests by forest type*

Forest type	No. of plots	Total biomass (air-dried, t/ha)
Upper Mixed Hardwood	42	310.35
Quercus spp.	21	231.12
Shorea robusta	63	187.22
Pinus wallichiana	9	141.95
Pinus roxburghii	68	123.73
Lower Mixed Hardwood	154	121.83
Terai Mixed Hardwood	72	96.00
Khair-Sissoo / Sissoo-Khair	4	70.55
Total/Average	**433**	**150.88**

The biomass of stems, branches and foliage in forests were approximately 94.10 t/ha, 46.43 t/ha and 10.34 t/ha, respectively. *Shorea robusta* had the greatest stem biomass and *Quercus* spp. had the greatest branch and foliage biomass. In total, *Quercus* spp. had the highest biomass, followed by *Shorea robusta* (Table 34).

Table 34: *Air-driedbiomass by species and tree component (t/ha)*

Tree species	Air-dried tree component biomasses (t/ha)			
	Stem	Branch	Foliage	Total
Quercus spp.	14.45	13.87	3.06	31.38
Shorea robusta	21.19	4.81	1.38	27.37
Pinus roxburghii	15.52	4.04	0.78	20.34
Rhododendron spp.	4.62	3.48	1.15	9.25
Schima wallichii	6.28	2.01	0.29	8.59
Castanopsis spp.	3.82	3.02	0.19	7.02
Alnus spp.	2.33	2.66	0.26	5.24
Lyonia spp.	1.85	1.49	1.11	4.45
Terminalia alata	3.00	1.20	0.15	4.36
Pinus wallichiana	1.87	1.03	0.55	3.44

Lagerstroemia parviflora	1.36	0.55	0.08	1.99
Haldina cordifolia	0.46	0.18	0.02	0.67
Acacia catechu	0.40	0.16	0.03	0.58
Other species	16.96	7.94	1.31	26.20
Total	**94.10**	**46.43**	**10.34**	**150.88**

Quality Assurance of Forest Inventory

Of the 31 plots that were re-measured, 17 had the same number of trees as were originally measured, and the maximum difference in the other plots was two. The total number of trees measured during the quality-assurance measurements was 614, which is three trees less than original count. The maximum difference in the number of trees was 58 per hectare. The average Basal Area per hectare decreased from 18.31 m^2/ha originally to 18.22 m^2/ha during the quality assurance measurements. The tree enumeration was almost unbiased – the mean difference in the number of enumerated trees was 0.10. The standard deviation of the difference in the number of enumerated trees was 4.94%.

5.5 Soils of Middle Mountains Forests

A total of 314 soil profiles from forest stands in 165 clusters were analysed for soil texture, bulk density, moisture content in the field, and percentage of SOC. Soil textures in Middle Mountains were somewhat unevenly distributed across Development Regions. Sandy loams were slightly more represented in Eastern, Central, and Western Development Regions than in Mid-Western and Far-Western Development Regions, while sandy clay loams were more commonly found in Western and Mid-Western Development Regions than elsewhere. Other soil texture types did not show any set pattern or were too rare.

Distribution of Soil Organic Carbon (SOC) in Middle Mountains Forest Soils

The overall average SOC stock, 54.33 (±1.29) t/ha, was higher in Middle Mountains than the stocks of lower belt of Churia and Terai physiographic regions. Even in similar forest types, there was more SOC in Middle Mountains than either in Churia or the Terai (DFRS, 2014a; 2014b). Higher SOC values were not found in the organic layer on top of the soil, but in deeper soil.

While much of the total SOC is confined to the top 10 cm, the fact that average SOC content decreases slowly in deeper soil layers suggests that much more SOC could be found below the 30 cm topsoil layer. In the Terai and Churia, over one-third of the total forest carbon stock was found in the organic carbon in the topsoil (DFRS, 2014a; 2014b). In Middle Mountains forests, this proportion was even higher, around 45.77%(Figure 17).

The soil layer consisting of topsoil from soil surface down to 30 cm depthis the most vulnerable part of soil organic matter. In thick soils, tree roots often penetrate deep, providing organic matter input by means of fine root turnover. Therefore, the actual soil organic carbon stock, typically assessed up to 1 m depth, may greatly exceed the values measured here. We can only roughly estimate SOC in a soil layer 1 m deep. If we conservatively assume that the average fine soil fraction bulk density of the deepest measured 20–30 cm layer (1.05 g/cm^3)is valid for the 30–100 cm layer as well and that SOC content there is about 0.5%, as the data shown in Figure18suggests, the possible content of SOC in 1 m becomes as high as 360 t/ha. This would suggest that SOC stock is six times more than the 54 t/ha FRA-Nepal found in a layer 30 cm deep. This high SOC value suggests that Middle Mountains forests could experience large carbon losses through careless changes in management and land use.

SOC stocks were not related simply to soil texture; they also reflected the site's elevation above sea level and were positively correlated with topsoil moisture content. The altitude effect seemed to be related to the occurrence of different forest types at different altitudes (Figure 18). *Shorea robusta* and *Pinus roxburghii* forests, which had the lowest SOC values, occupied the lowest altitudes while UMH and *Quercus*spp. forests, which had the highest SOC values, were found at altitudes exceeding 200 m. *Pinus* forests formed an intermediate type with respect to altitude preference and SOC accumulation.

The reason for high SOC stocks in upper Middle Mountains is probably due to the high productivity of the ground vegetation, trees, climbers, and epiphytes attributable to the high air humidity supported by low level clouds frequently meeting the canopy. In addition, the decomposition rate of carbon in the soils of Middle Mountains is likely lower than rates in the Churia or Terai because temperatures are lower at higher elevations.

Differences in forest land topography and land use, among other factors, may have affected the apparent differences in average SOC stocks between the different Development Regions. It is evident that a greater proportion of forests in Central, Western and Mid-Western Development Regions are lower-altitude forests than those in Eastern and Far-WesternDevelopment Regions (Figure 18). In Central Development Region, medium altitude *Pinus wallichiana* and *Quercus* spp. forests were responsible for the highest SOC accumulations, while in Western and Far-Western Development Regions, that role was taken by UMH forests.

The average carbon stock of litter and woody debris in forest was 1.65 t/ha (Table 37). The litter and woody debris stocks measured in Middle Mountains did not adhere to the SOC–altitude response noted for soil (Figure 18). Because only the litter and debris store present during the instant of visit was examined, it cannot represent the rate of annual above-ground input to SOC stores. In order to obtain the rate (units of mass per area and time), litter fall on a specific area should be collected over longer term by using traps. Both above-ground litter (leaves, woody debris) and below-ground organic litter (dead roots) contribute to the accumulation of SOC. With the present stock data we are not able to quantify these inputs. The possible reasons for the low-altitude–low SOC and high altitude–high SOC phenomena are differences in rate of decomposition of organic litter. At low altitudes with prevailing high temperatures, the decomposition rate is high, meaning that most of the organic litter gets oxidised to carbon dioxide. On the contrary, at high altitudes the turnover rate of both above-ground and below-ground litter can be longer, supporting a higher rate of SOC accumulation than at low altitudes (Table 35).

Table 35: *Soil characteristics, litter and wood debris per hectare and number of clusters with soil data by forest type*

Forest type	Bulk density	SOC (%)	Stoniness (%)	SOC (t/ha) (SE)	Litter and woody debris (t/ha)	No. of clusterswith soil data
Khair-Sissoo / Sissoo-Khair	1.35	1.91	11.64	43.31 (265.36)	0.87	3
Lower Mixed Hardwood	1.04	2.04	9.97	49.28 (1.83)	1.62	77
Pinus roxburghii	1.11	1.55	7.43	42.11 (7.80)	1.38	23
Pinus wallichiana	0.83	2.43	9.40	51.56 (150.67)	0.87	4
Quercus spp.	0.89	4.13	12.59	86.15 (46.84)	2.49	13
Shorea robusta	1.11	1.43	8.70	37.66 (4.96)	1.75	27
Shrub	1.12	3.40	7.94	80.05 (217.87)	1.41	8
Terai Mixed Hardwood	1.20	1.63	9.56	42.02 (31.86)	1.94	9
Upper Mixed Hardwood	0.77	5.40	9.19	100.62 (46.00)	1.81	16

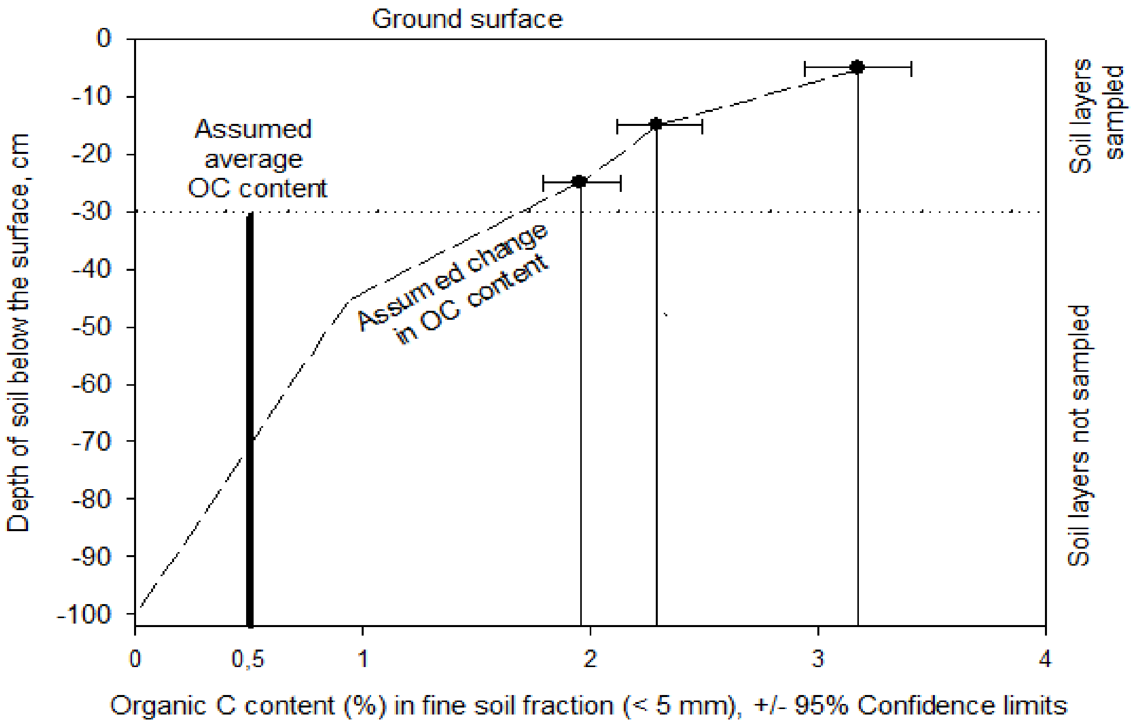


Figure 17: *A schematic presentation of soil organiccarbon (SOC) by soil depth*

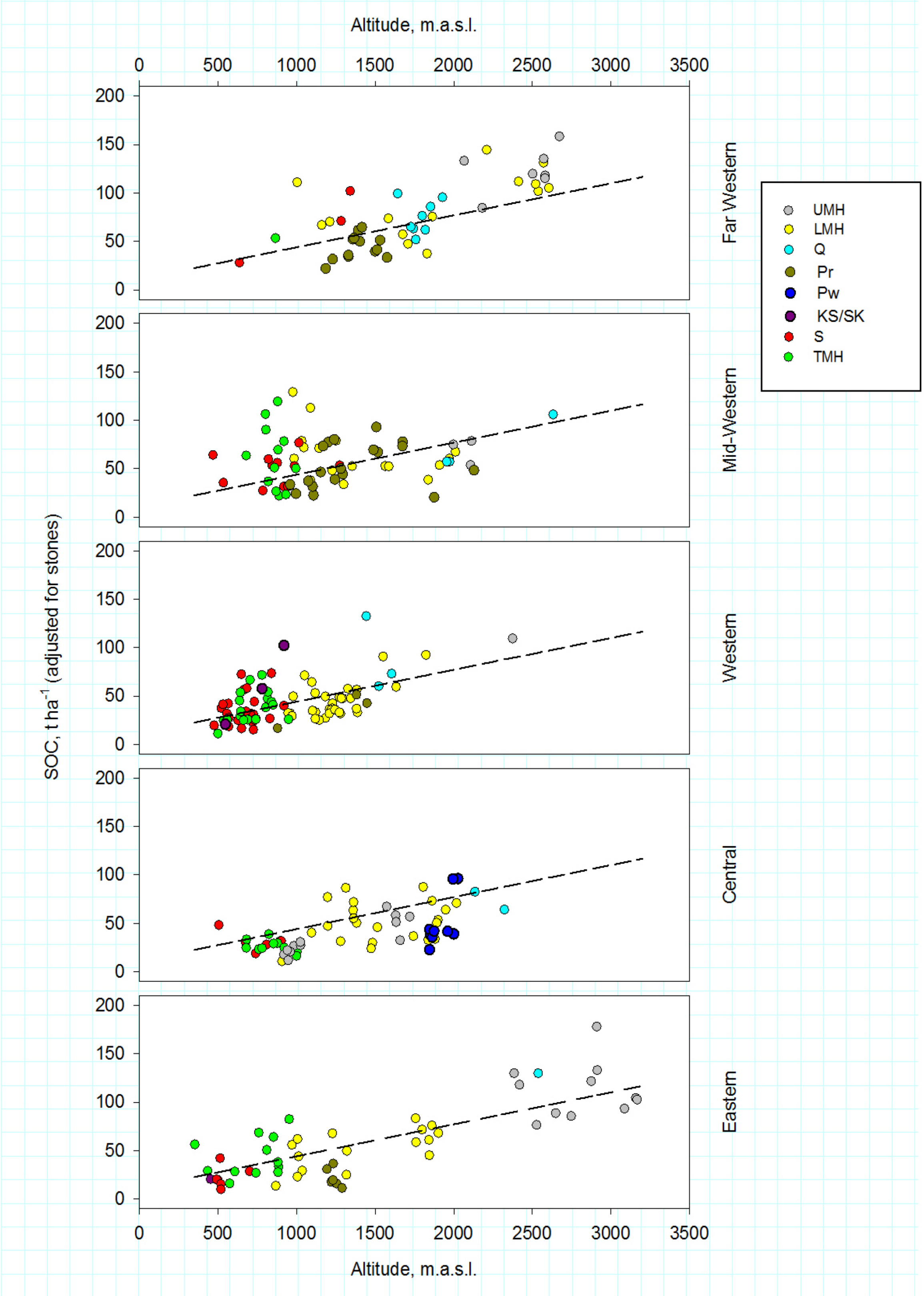


Figure 18: *Soil Organic Carbonstock by forest type, altitudeand Development region*

The overall average SOC stock was 54.33 (±1.29) t/ha and litter and woody debris was 1.65(±0.002) t/ha (Table 37) on Forest. The highest SOC (76.80 t/ha), and litter and woody debris (2.21 t/ha) was found in Far-Western region, whereas the least SOC (43.37 t/ha), and litter and woody debris (1.28 t/ha)was in Western Region (Table 36).

Table 36: *Soil organic carbon, litterand debris by Development Region*

Region	SOC (SE)* t/ha	Litter + Woody Debris (SE) t/ha	Number of Clusters with Soil Carbon Data	OC in 0-30 cm + Litter and Woody Debris, t/ha
Eastern	57.17 (24.61)	1.52 (0.0160)	52	58.69
Central	46.30 (8.91)	1.52 (0.0170)	67	47.82
Western	43.37 (4.65)	1.28 (0.0073)	83	44.65
Mid-Western	58.37 (12.37)	1.95 (0.0235)	66	60.32
Far-Western	76.80 (29.75)	2.21 (0.0582)	46	79.01

**SE of SOC at regional level and by forest types exceeds the minimum SE, therefore may need to be used cautiously at region levels*.

5.6 Carbon Stock in Middle Mountains Forests

The total carbon stock in Middle Mountains forests was 311.28million tonnes(138.11t/ha). Of the total carbon pool in the forest, tree component contributed 59.47%; litter and debris 1.19%, and soil 39.34% (Table 37).

Table 37: Carbon pool in forests

By tree component	
Oven dry biomass (t/ha)	174.75
Carbon (t/ha)	82.13
Total Carbon in tonnes	185,113,360
Total Carbon in tree component (million tonnes)	185.11
By litter and debris	
Carbon (t/ha)	1.65
Total Carbon in tonnes	3,718,782
Total Carbon in litter and debris component (million tonnes)	3.72
By soil	
Carbon (t/ha)	54.33
Total Carbon in tonnes	122,449,334
Total Carbon in soil component (million tonnes)	122.45
Total	
Carbon (t/ha)	**138.11**
Total Carbon in tonnes	311,281,475
Total Carbon in Middle Mountains Forests (million tonnes)	**311.28**

5.7 Middle Mountains Forest Biodiversity

Tree Species Diversity

Altogether 326 tree species belonging to 200 genera and 89 families were recorded from the sample plots in Middle Mountains forests. Fabaceae, with 19 genera and 41 species, was the largest family followed by Lauraceae, with 6 genera and 21 species: Fi*cus*, which comprises 15 species, was the largest genera. The average number of tree species (α-diversity or species richness) recorded per plot was 15. The tree data are compositional and have a gradient length (β-diversity as determined by DCA analysis) of 11.60SD units, a high value indicating that the turnover of tree species from one plot to the next was very high.

The high Eigenvalues (CCA first axis = 71.56% and CCA second axis = 31.51%) indicate that tree species heterogeneity was explained mostly by environmental variability. Good dispersion of species along the ordination plot was observed, which indicated that the species heterogeneity was most explained by the first axis due to a high β-diversity. Some tree species, such as *Sorbus* *ursina, Lyonia ovalifolia, Rhododendron arboreum, Rhododendron barbatum,* and *Quercus semecarpifolia*, exhibited a strong positive correlation with altitude and soil water while species like *Shorea robusta, Terminalia alata, Lagerstroemia parviflora andSchima wallichii* exhibited a strong negative correlation with these variables. Soil carbon was mostly recorded from *Quercus floribunda, Eurya acuminata, Cupressus torulosa* and *Prunus napaulensis* and showed strong negative correlations with bulk density and aspect (Figure 19).

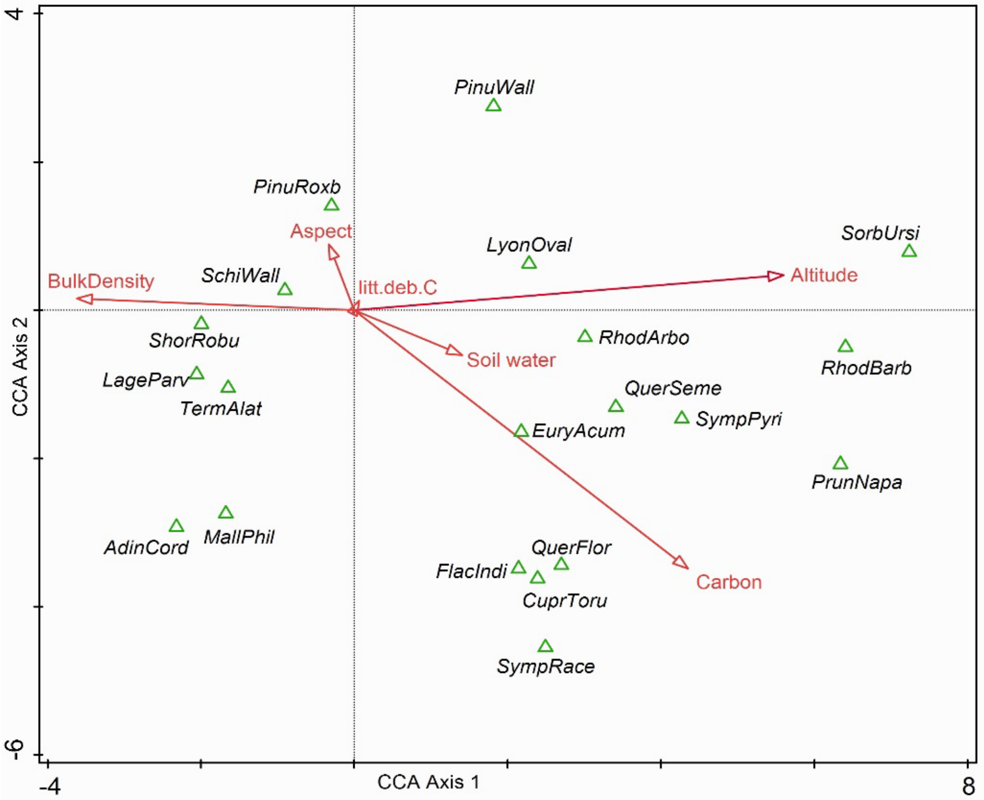


***Figure 19:** Ordination graph of tree speciesand relationship with environmental variability*

Note: Predictor variables are represented by red arrows (litt.debC = litter debris carbon content, BulkDensity = soil bulk density, Carbon = soil carbon content *etc.*) and tree species by green triangles. The species are listed by the first four letters of both the genus and the species. They include AdinCord :*Adina cordifolia,* CuprToru :*Cupressus torulosa*, EuryAcum :*Eurya acuminata*, FlacIndi :*Flacourtia indica*, LageParv*: Lagerstroemia parviflora,* LyonOval:*Lyonia ovalifolia,* PinuRoxb*: Pinus roxburghii,* PinuWall :*Pinus wallichiana*,PrunNapa*: Prunus napaulensis,* QuerFlor:*Quercus floribunda,* QuerSeme*:Quercus semecarpifolia,* RhodArbo*: Rhododendron arboreum,* RhodBarb*: Rhododendron barbatum,* ScimWall*: Schima wallichii,* ShorRobu*: Shorea robusta,* SorbUrsi*: Sorbus ursina,* SympPyri*: Symplocos pyrifolia,* SympRace :*Symplocos racemose* and TermAlat*: Terminalia alata.*

Similarly, the other ordination plot of species and forest types also revealed high Eigenvalues (CCA first axis = 68.80% and CCA second axis = 34.99%). The species were well distributed along the first axis and highly correlated with the predictor variables. Altitude has strong correlation with *Quercus*, *Pinus wallichiana* and Upper Mixed Hardwood (UMH) forests. Sal forests, Terai Mixed Hardwood (TMH) and Agricultural lands had strong negative correlation with altitude. Tree species like *Betula utilis, Rhododendron barbatum, Lyonia ovalifolia, Quercus semecarpifolia,* etc.were always recorded from high altitude while species such as *Lagerstroemia parviflora, Terminalia alata, Shorea robusta, Haldina cordifolia, Syzygium cumini, Symplocos pyrifolia,* etc. were found in low altitudes. On the upper edge of plot, both the pine forests showed very low species richness (Figure 20).

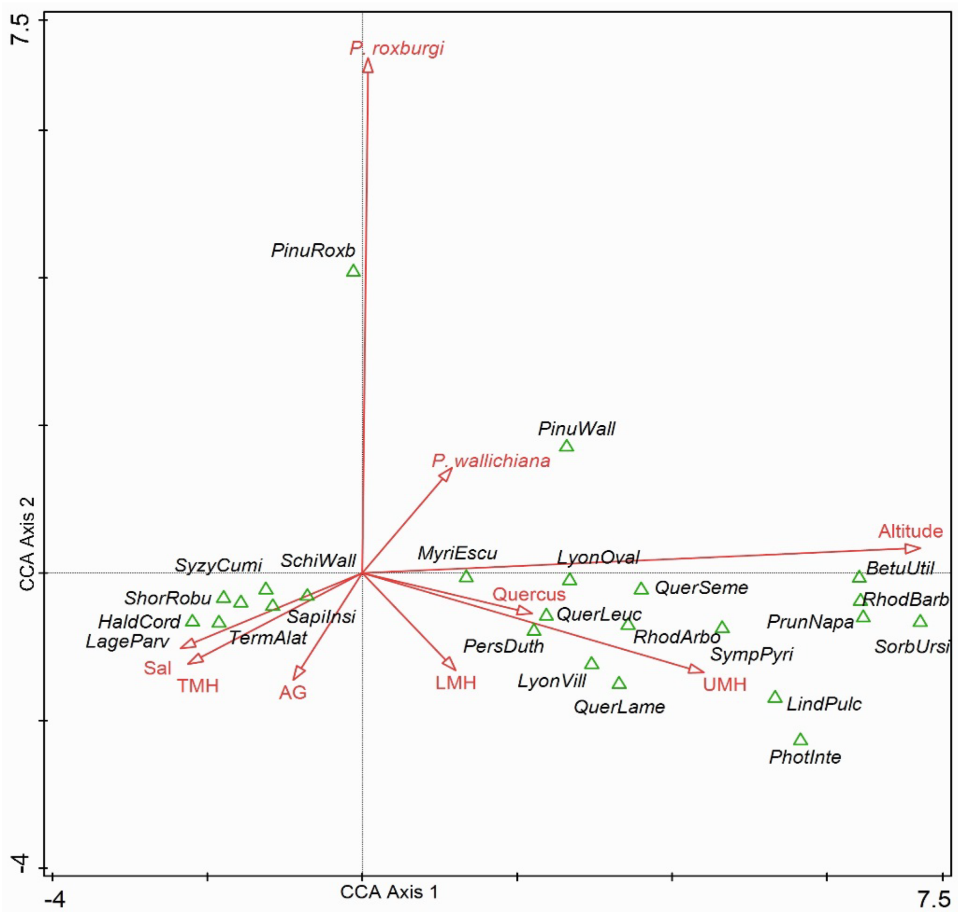


Figure 20: *Ordination graph of tree species with forests types*

Note: Predictor variables are represented by red arrows, (TMH–Terai Mix Hardwood, LMH–Lower Mix Hardwood, UMH–Upper MH, AG = Agriculture *etc.*) and tree species by green triangles. The species are listed by the first four letters of both the genus and the species. They include AdinCord : *Haldina cordifolia*, BetuUtil:*Betula utilis*, CleisOper:*Cleistocalyx operculatus*, FuciNeri : *Ficus neriifolia*, FicuSemi:*Ficus semicordata*, HaldCord:*Haldina cordifolia*, MangIndi:*Mangifera indica*, *LageParv: Lagerstroemia parviflora, ListMono:Litsea monopetala,LyonOval*:*Lyonia ovalifolia,* LindPulc:*Lindera pulcherrima, LyonVill : Lyonia villosa,* PinuRoxb*: Pinus roxburghii,* PinuWall: *Pinus wallichiana*, *PrunNapa: Prunus napaulensis,* PersDuth:*Persea duthiei, QuerLana: Quercus lanata,* QuerLana*: Quercus lanata, QuerLeuc: Quercus leucotrichophora, QuerSeme: Quercus semecarpifolia, RhodArbo: Rhododendron arboreum,* RhodBarb:*Rhododendron barbatum, SapiInsi : Sapium insigne, ScimWall: Schima wallichii,* ShorRobu*: Shorea robusta, SympPyri: Symplocos pyrifolia,* SyzyCumi*: Syzygium cumini*andand *TermAlat: Terminalia alata.*

Tree Species Occurrence

*Schima wallichii*was the most common tree species present in 32% of inventoried plots. The other commonly occurring species are *Shorea robusta* (30%), *Pinus roxburghii* (25%) and *Rhododendron arboreum* (16%). A histogram of tree species of more than 4% occurrence in the sample plots are shown in Figure 21. One hundred twenty eight species occurred only a single time.

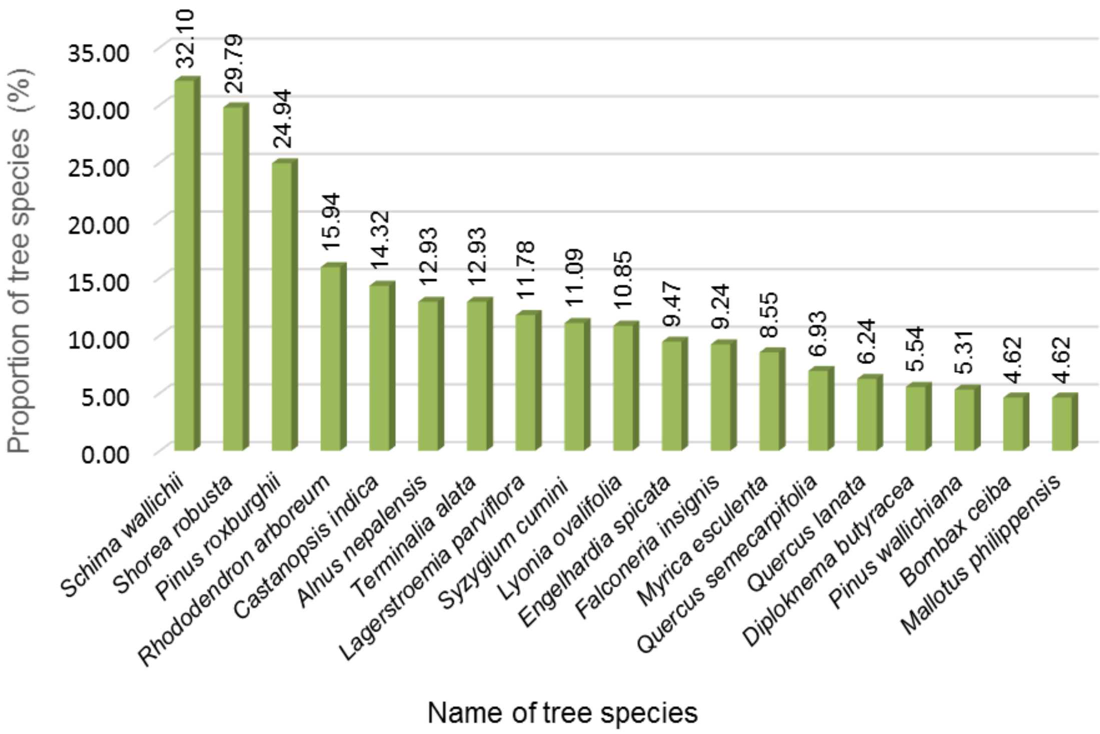


Figure 21:*Proportional distribution of* major tree species in the inventoried plots

The value of the Shannon-Weaner diversity index ($\bar{H}$) for Middle Mountains region as a whole was 2.75. The index for LMH (n = 154 and 145 species) was 2.11; for *Pinus roxburghii*(n = 68 and 38 species) was 1.76; for *Shorea robusta*(n = 63 and 49 species) was 1.74; for *Pinus wallichiana*(n = 9 and 14 species) was 0.84; for *Quercus* spp. (n = 21 and 24 species) was 1.24; for UMH (n = 42 and 66 species) was 1.58; for TMH (n = 72 and 92 species) was 1.80; for agriculture (n = 206 and 140 species) was 2.22; and for all other types (n = 51and 58 species) it was 1.63.

Shrub Species Diversity

Altogether, 244 shrub species belonging to 161 genera and 69 families were recorded in Middle Mountains forests plots. Fabaceae, with 17 genera and 26 species, was the largest family. Twenty-five families included only a single genus and a single species. The histogram of species distribution showed that over 20 shrub species occurred at abundance frequencies of more than 1%. The most distributed species (those with the highest abundance frequency percentages) were *Woodfordia fruticosa*, which was found in over 14% of the total plots, *Inula cappa* (7%), *Rhus parviflora* (about 7%), *Berberis asiatica* (over 6%) and *Daphne bholua* (nearly 6%) (Figure22).

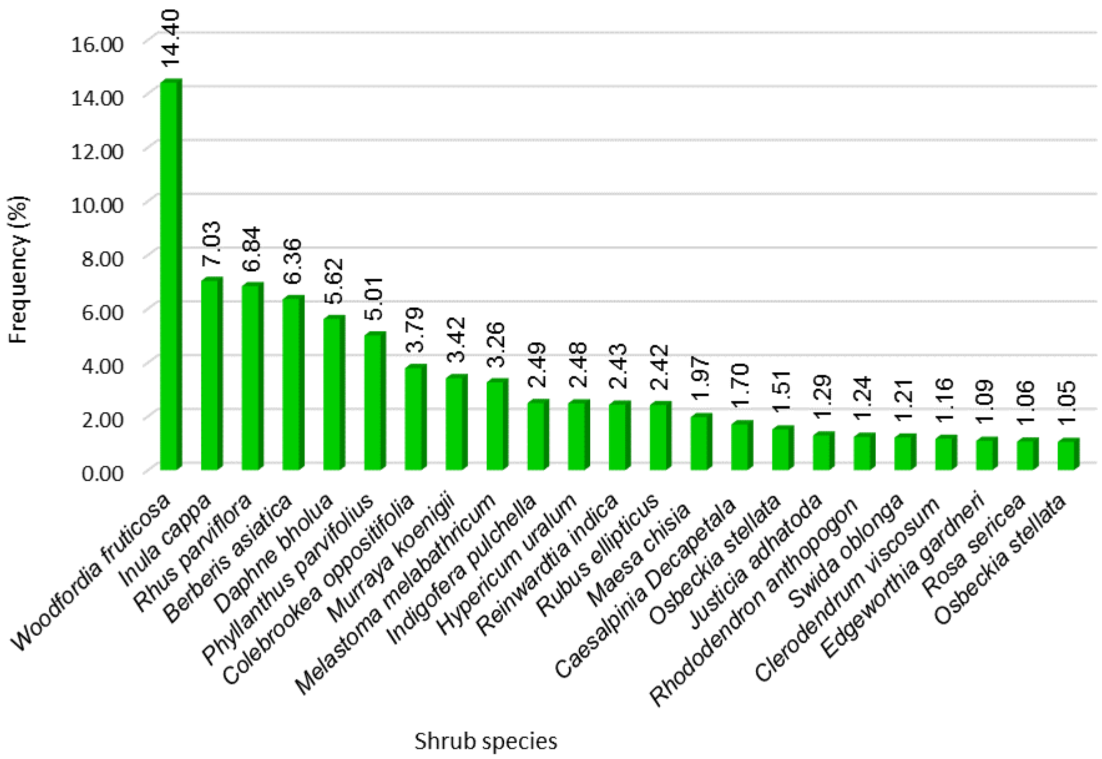


Figure 22: *Frequency of major shrubs in plots*

The shrub species data were compositional and have a gradient 10.40 SD units long (the length of the gradient, or β-diversity), a high value indicating a very high shrub species turnover from one plot to the next. The high Eigenvalues (DCA first axis = 71.14% and DCA second axis = 69.54%) indicate that shrub species heterogeneity can be explained mostly due to environmental variability. Most species were distributed randomly in the CCA graph, indicating a high β-diversity.

The ordination graph shows that the maximum species abundance was found along the first axis.*Edgeworthia gardneri, Viburnum nervosum, Rhododendron anthopogon, Hypericum choisianum, Daphne bholua*and *Rhamnus nepalensis* showed strong positive correlation with UMH and high altitudes in Eastern Development region whereas species like *Woodfordia* *fruticosa, Melastoma melabathricum* and *Swida oblonga* had strong negative correlations with both these variables and are found in Sal and *Pinus* forests in dry soils with high bulk densities. Species like *Berberis asiatica, Mahonia napaulensis* and *Rosa sericea* showed positive correlations with soil moistureathigh altitudes. *Edgeworthia gardneri, Rhododendron lindleyi, Rhododendron lepidotum* and *Sarcococca hookeri* showed strong positive correlations with soil carbon (Figure 23).

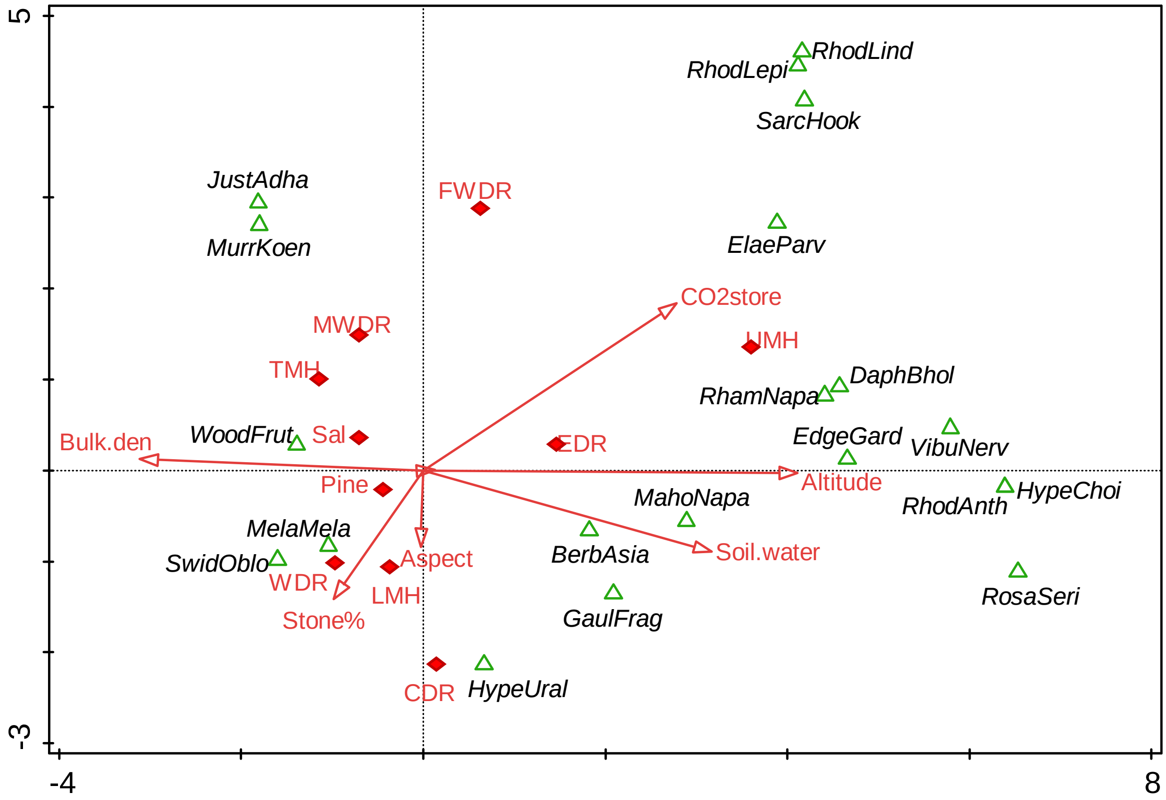


Figure 23: *Relationships among shrub species and environmental variables*

Note: Predictor variables are represented by red arrows, response variables by red bricks (EDR–Eastern Development Region, WDR–Western Dev. Region, Middle WDR and Far WDR; TMH–Terai Mixed Hardwood, LMH–Lower Mixed Hardwood, UMH–Upper Mixed Hardwood, Quer–*Quercus etc.*) and shrub species by green triangles. The species are listed by the first four letters of both the genus and the species. They include *BerbAsia: Berberis asiatica, DaphBhol: Daphne bholua, EdgeGard: Edgeworthia gardneri, ElaeParv: Elaeagnus parvifolia, GaulFrag: Gaultheria fragrantissima, HypeChoi: Hypericum choisianum, HypeUral: Hypericum uralum, JustAdha: Justicia adhatoda, MahoNapa: Mahonia napaulensis, MelaMela: Melastoma melabathricum, MurrKoen: Murraya koenigii, RhamNapa: Rhamnus nepalensis, RhodAnth : Rhododendron anthopogon, RhodLind:Rhododendron lindleyi, RhodLepi: Rhododendron lepidotum, RosaSeri: Rosa sericea, SarcHook: Sarcococca purniformis, SwidOblo: Swida oblonga, VibuNerv: Viburnum nervosum*and *WoodFrut: Woodfordia fruticosa.*

Herbaceous Species Diversity

Altogether, 547 species of herbaceous plants (including flowering plants and pteridophytes) belonging to 356 genera and 99 families were recorded in Middle Mountains. Of the 99 families, 80 were flowering plants divided into 316 genera and 476 species and the remaining 19 families were pteridophytes belonging to 39 genera and 70 species. Poaceae, comprising 64 genera and 93 species, was the largest family and Asteraceae, comprising 33 genera and 57 species, was the second largest family. The Orchidaceaefamily, which was represented by 14 genera and 15 species, falls under the Appendix II of CITES for 30 herb families; there was only one genus and one species.

The histogram of herb species distribution showed that 20 species had frequency rates of more than 1%. The most abundant species (those highest in distribution) were *Capillipedium assimile*, which was found in nearly 12% of plots, *Chromolena odoratum* (about 10%), *Dicranopteris linearis* (5%) and *Imperata cylindrica, Arundinella nepalensis, Nephrolepis auriculata*and *Ageratum conyzoides* (each over 3%) (Figure 24).

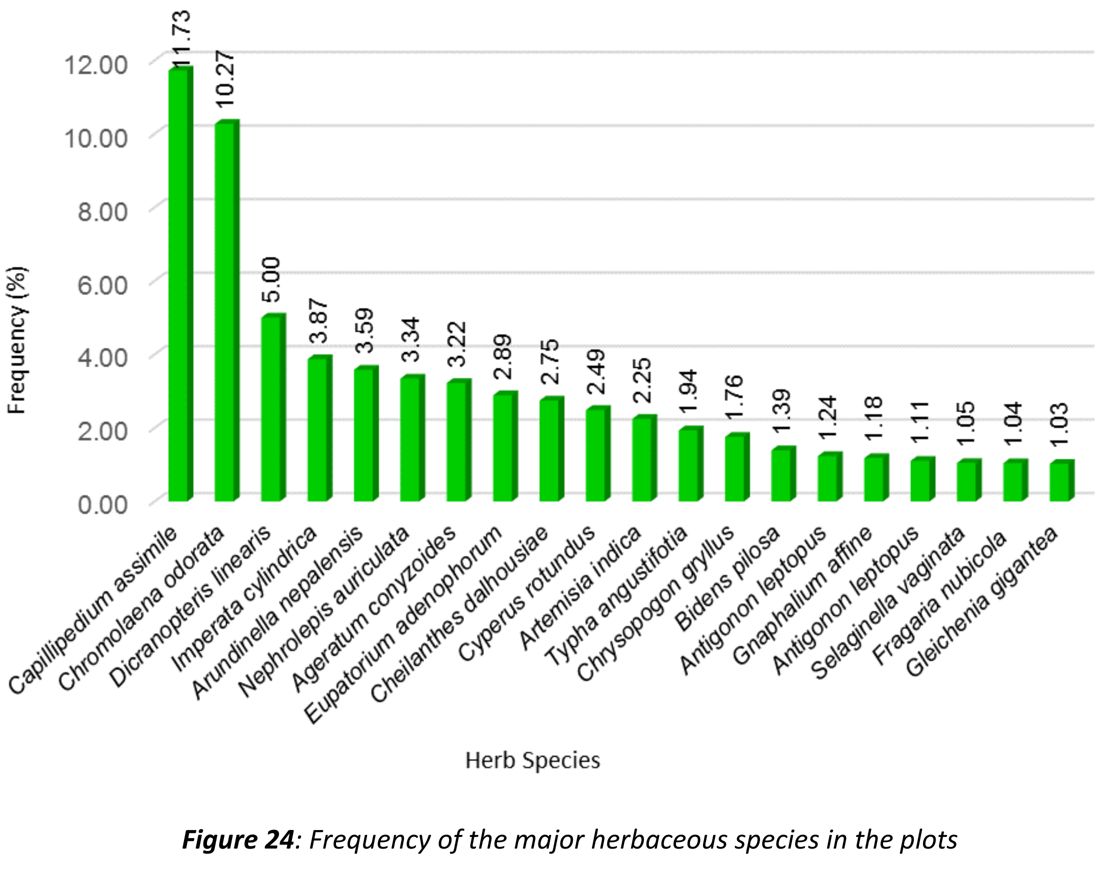


Figure 24*: Frequency of the major herbaceous species in the plots*

The response data are compositional and have a gradient 10.50 SD units long (the β-diversity value); a high value indicating that there is a very high turnover of herbaceous species from one plot to the next. The Eigenvalues (CCA first axis = 53.00% and second axis = 40.68%) indicate that the heterogeneity of herb species can be explained mostly due to environmental variability. Most of the species were dispersed towards the corner of the graph, indicating high β-diversity in the region.

Multivariate analysis of the herbaceous species revealed that altitude was positively correlated with *Violabiflora, Violapilosa, Violathomsonii, Violawallichiana, Potentilla peduncularis, Thamnocalamus spathiflorus*and *Chlorophytum nepalense*, but negatively correlated with *Capillipedium assimile, Chromolaenaodorata* and *Themeda triandra*. Altitude showed strong positive correlations with UMH forests, soil carbon and soil moisture in Far-WesternDevelopment Region. It also revealed that high altitudes and UMH forests were rich in herbaceous species. Lower elevations correlated with *Shorea robusta*, TMH and LMH forests and were found mostly in Western Development Region (Figure 25).*Pinus* and *Shorea robust* forests have high bulk densities of soil. Litter carbon is positively correlated with *Dennstaedtia appendiculata* and *Anaphalis triplinervis*.

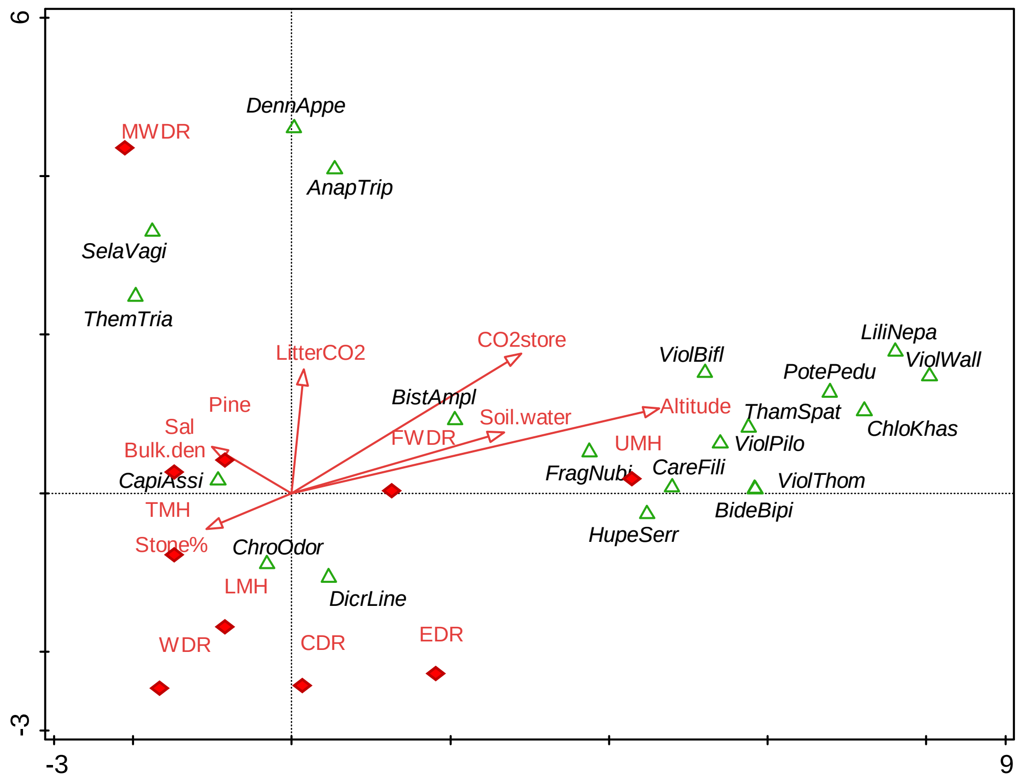


Figure 25: *Relationships among herbs, trees and shrubs*

Note: Predictor variables are represented by red arrows, response variables by red bricks, (EDR - Eastern Development Region, CDR - Central Development Region, WDR - Western Development Region, MWDR–Mid-Western Development Region and FWDR–Far-Western Development Region; TMH–Terai

MixedHardwood, LMH–Lower Mixed Hardwood, UMH–Upper MH, *etc.*) and herbaceous species by green triangles. The species are listed by the first four letters of both the genus and the species. They include AnapAdan:*Anaphalis adanata,* AnapTrip*: Anaphalis triplinervis,* BideBipi:*Bidensbipinnata,* BistAmpl:*Bistorta amplexicaulis,* CapiAssi:*Capillipedium assimile,* CareFili:*Carexfilicina,* ChloKhas:*Chlorophytum nepalense,* ChroOdor:*Chromolaena odorata,* DennAppe :*Dennstaedtia appendiculata,* DicrLine:*Dicranopteris linearis,* FragNubi:*Fragarianu bicola,* HupeSerr:*Huperzia serrata,* LiliNepa:*Lilium nepalense,* PotePedu:*Potentilla peduncularis,* SelaVagi:*Selaginella vaginatam,* ThamSpat:*Thamnocalamuss pathiflorus,* ThemTria:*Themeda triandra,* ViolBifl:*Violabiflora,* ViolPilo:*Violapilosa,* ViolThom:*Violathomsonii* and ViolWall:*Violawallichiana.*

Invasive Species

Shrub Invasive Species

Lantana camara, Clerodendrum canescens, *Duranta repens*, *Eriobotrya dubia*, *Ficus subincisa*, *Hypecoum parviflorum*, *Premna interrupta* and *Rubus alexeterius w*ere the major invasive alien plant species recorded.*Chromolena odorata,*anexotic and invasive species was found in most of the plots in Middle Mountains Forests.*Ageratina adenophora*, an exotic and invasive species was also found in many plots.According to Siwakoti (2012), alien plants of Nepal were classified into high threat, low threat and insignificant threat categories. In Middle Mountains, herb species like *Chromolaena odorata,Ageratina adenophora* and *Eichhornia crassipes* fall under high threat, *Ageratum conyzoides, Argemone mexicana, Hyptis suaveolens and Leersia hexandra* in low threat and *Bidens pilosa* and *Mimosa pudica* were kept in insignificant categories. *Chromolaena odorata*, a very aggressive invasive species, was most common in LMH and TMH forests in Western and Central Development Regions.

Climbers and Epiphytes and their Host Species

Altogether, 109 species of climbers belonging to 60 genera and 30 families and 90 species of epiphytes with 62 genera and 30 families were also found in Middle Mountains region. Among the climbers, Vitaceae (7 genera, 13 species), Cucurbitaceae (8 genera and 12 species) and Fabaceae (7 genera and 10 species) have the greatest number of species. The epiphytic group, Orchidaceae, with 19 genera and 32 species (all falling under Appendix II of the CITES) was the largest family and Polipodiaceae (7 genera and 12 species) was the second largest family.The most common climbers were *Dioscorea bulbifeara*, *Dioscorea pentaphylla*, *Smilax ovalifolia* and *Bauhinia vahlii.*The most common host tree species recorded were *Shorea robusta*, *Schima wallichii, Castanopsis indica*, *Rhododendron arboretum* and *Quercus semecarpifolia.*

Non-timber Forest Products

According to the social survey, 868 different species of flora were used as NTFPs in Middle Mountains. A total of 283 species of trees belonging to 169 genera and 82 families; 190 species of shrubs belonging to 128 genera and 64 families; and 291 species of herbs (including sedge) belonging to 164 genera and 66 families were used as NTFPs, as were 29 species of ferns and fern-allies belonging to 22 genera and 16 families. In addition, 75 species of climbers belonging to 51 genera and 25 families were also used as NTFPs. Among the floral community, the families ofFabaceae (32 genera and 63 species) and Poaceae (44 genera and 63 species) were the largest.

A total of 435 species of NTFPs were used for medicinal purposes. The most commonly used were *Phyllanthus emblica* (61% of plots), *Terminalia chebula* (46% of plots) and *Terminalia bellirica* (41% of plots). One hundred and thirty-five species of NTFPs were used for religious purposes; of them, *Ficus religiosa, Ficus bengalensis, Aegle marmelos*and *Shorea robusta* were the most significant. Altogether, 199 species of NTFPs were consumed as fruit and nuts. *Rubus ellipticus*, *Myrica esculenta*, *Syzygium cumini*and *Phyllanthus emblica* were the plant species whose fruits were most consumed. Fodder was derived from 531 plant species, most commonly *Ficus semicordata, Terminalia alata*, *Woodfordia fruticosa* and *Castanopsis indica*. There were 94 species of fiber and fiber-yielding plants. The most common were *Bauhinia vahlii, Diospyros malabarica, Girardinia diversifolia*and *Sterculia villosa*.

Local people of Middle Mountains region used 83 species of plants as insecticides and herbicides, primarily *Falconeria insignis, Artemisia indica, Zanthoxylum armatum* and *Justicia adhatoda*. Sixty species were used to make beverages. Among them the most common were *Rhododendron arboreum*, *Aegle marmelos*, *Diploknema butyracea* and *Myrica esculenta*. The most-used multi-purpose NTFPs in the region were *Diploknema butyracea*(20 uses); *Pinus roxburghii* (16 uses); *Dioscorea bulbifera*, *Bombax ceiba, Rhododendron arboreum*, *Phyllanthus emblica* and*Syzygium cumini* (15 uses each); *Shorea robusta, Zanthoxylum armatum*, *Mangifera indica* and*Myrica esculenta* (14 uses each); and *Asparagus racemosus* (12 uses). Of the total 435 species of NTFPs, 299 (69%) were used for one purpose only.

The highest numbers of plants (39.92% tree species, 22.60% shrub species, 27.12% herb species and 10.36% fern/climbers) were used as fodder. Medicinal usage of plant in Middle Mountains wassecond highest (28.97 of tree species, 21.61% of shrub species, 34.71% herb species and 14.71% fern/climbers). The least numbers of plants were found to be used as bio-fuel (Table 38).

Table 38: *Usage of Plant-NTFPs in Middle Mountains region*

Usage purpose	**Tree (%)**	**Shrub (%)**	**Herb/grass (%)**	**Climber/ Ferns,sedge**	**Total No.**
Fodder	**39.92**	**22.6**	**27.12**	**10.36**	**531**
Medicinal plants	**28.97**	**21.61**	**34.71**	**14.71**	**435**
Animal bedding	**55.12**	**20.14**	**17.31**	**7.42**	**283**
Fruit and nuts	**47.75**	**33.33**	**9.01**	**9.91**	**222**
Construction material	**57.92**	**12.57**	**21.86**	**7.65**	**183**
Utensils, handicrafts	**61.85**	**17.92**	**17.34**	**2.89**	**173**
Religious plant	**49.32**	**15.54**	**25**	**10.14**	**148**
Veterinary medicine	**30.33**	**22.13**	**31.15**	**16.39**	**122**
Support for climbers/*Thankro*	**63.48**	**26.96**	**9.57**	**0**	**115**
Vegetables	**17.27**	**12.73**	**46.36**	**23.64**	**110**
Fibre and fiber yielding	**34.07**	**23.08**	**24.18**	**18.68**	**91**
Spices, condiments and other flavorings	**40.91**	**17.05**	**32.95**	**9.09**	**88**
Insecticieds and herbicides	**46.43**	**29.76**	**19.05**	**4.76**	**84**
Seeds	**69.86**	**15.07**	**8.22**	**6.85**	**73**
Beverage	**50.82**	**24.59**	**19.67**	**4.92**	**61**
Ornamentals	**42.37**	**18.64**	**16.95**	**22.03**	**59**
Fumitory and masticator materials	**63.79**	**13.79**	**13.79**	**8.62**	**58**
Drying/tanning	**62.5**	**21.43**	**10.71**	**5.36**	**56**
Soap/cosmetics	**38.46**	**15.38**	**36.54**	**9.62**	**52**
Exudates	**74.47**	**23.4**	**2.13**	**0**	**47**
Vegetable oils and fats	**51.52**	**27.27**	**12.12**	**9.09**	**33**
Legumes or pulses	**41.38**	**17.24**	**13.79**	**27.59**	**29**
Starches and cellulose products	**26.92**	**19.23**	**23.08**	**26.92**	**26**
Biofuel	**68.42**	**15.79**	**10.53**	**5.26**	**19**

Animal Derivatives

Altogether 72 faunal species (60 genera from 36 families) were used as animal derivatives in Middle Mountains. Of them, 28 species were mammals, 34 were birds, two were amphibians, two were reptiles and six were insects. According to the social survey, wild animals were most commonlyused as meat (44.44%mammals and 51.85% birds). Some of the animals were also found to be used for religious purposes (Table 39).

Table 39: *Usage of animal derivatives in Middle Mountains region*

Usage purpose	Mammal (%)	Birds (%)	Reptile (%)	Amphibia (%)	Insects (%)	Total No.
Bushmeat	44.44	51.85	3.70	0.00	0.00	54
Living animal	42.42	54.55	3.03	0.00	0.00	33
Other edible animal products	18.18	54.55	4.55	0.00	22.73	22
Hides, skins for trophies	84.21	10.53	5.26	0.00	0.00	19
Medicines from animals	66.67	16.67	5.56	11.11	0.00	18
Religious	46.67	40.00	13.33	0.00	0.00	15
Ornaments	50.00	40.00	10.00	0.00	0.00	10
Honey, beeswax	0.00	0.00	0.00	0.00	100.00	5
Tools	100.00	0.00	0.00	0.00	0.00	5
Drying/tanning	66.67	0.00	33.33	0.00	0.00	3

Conservation Status of Important Plant Species

Sixty-nine species were important according to their international as well as national conservation and trade status. Of them, three species (*Aster peduncularis* subsp. *Nepalensis, Himalayacalamus fimbriatus, H. porcatus, Homalium nepalense, Hypericum cordifolium*and *Ruta cordata*) are endemic. Seven species–*Cinnamomum glaucescens, Dalbergia latifolia, Juglans regia, Nardostachys jatamansi, Taxus wallichiana, Valeriana jatamansi* and *Shorea robusta* are legally protected under the 'Forest Regulations of 1995' (amended in 2001)and two species - *Dalbergia latifolia* and *Cycas pectinate* are classified as 'vulnerable' on the IUCN Red List (IUCN, 2013). Plants with high medicinal value and those medicinal plants prioritised for research and development (MPRD) or for agro-technology development (MPAD) by the Department of Plant Resources are listed in Table 40. Similarly, fourty four species from six families were included in appendix II of CITES list (DPR, 2014). Among them, Orchidaceae was the largest family having 25 genera and 39 species.

Table 40: *List of endemic, protected, threatened and medicinal value plant species*

S.N.	Species	Endemic	Threatened spp.		Commercially important spp.	
			P	IUCN	MPRD	MPAD
1	*Aconitum lethale* Griff. = *Aconitum spicatum* (Brühl) Stapf	..	..	..	√	..
2	*Asparagus racemosus* Willd.	..	..	..	√	√
3	*Aster peduncularis* Wall. ex Nees subsp. *nepalensis* Grierson	√	..	..	..	..
4	*Azadirachta indica* A. Juss.	..	..	..	√	..
5	*Bergenia ciliata* (Haw.) Sternb.	..	..	..	√	..
6	*Cinnamomum glaucescens* (Nees) Hand.-Mazz.[II]	..	√	..	√	√
7	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.	..	..	..	√	..
8	*Cycas pectinata* Buch.-Ham.	..	..	VU	..	..
9	*Dalbergia latifolia* Roxb.[III]	..	√	VU	..	..
10	*Dioscorea deltoidea* Wall. ex Griseb.	..	..	..	√	..
11	*Gaultheria fragrantissima* Wall.	..	..	..	√	..
12	*Himalayacalamus fimbriatus* Stapleton	√	..	..	..	..
13	*Himalayacalamus porcatus* Stapleton	√	..	..	..	..
14	*Homalium napaulense* (DC.) Benth.	√	..	..	..	..
15	*Hypericum cordifolium* Choisy	√	..	..	..	..
16	*Juglans regia* L.[I, III]	..	√		√	
17	*Nardostachys jatamansi* (D.Don) DC. = *Nardostachys grandiflora* DC.[II]	..	√	..	√	√
18	*Phyllanthus emblica* L.	..	..	..	√	..
19	*Piper longum* L.	..	..	..	√	√
20	*Rubia manjith* Roxb. ex Fleming	..	..	..	√	..
21	*Ruta cordata* D. Don	√	..	..	..	..
22	*Sapindus mukorossi* Gaertn.	..	..	..	√	..
23	*Shorea robusta* Gaertn.[III]	..	√	..	..	..
24	*Swertia chirayita* (Roxb. ex Fleming) Karsten	..	..	..	√	√
25	*Taxus wallichiana* Zucc. =*T. baccata* L[II].	..	√	..	√	√
26	*Tinospora sinensis* (Lour.) Merr.	..	..	..	√	√
27	*Valeriana jatamansi* Jones[II]	..	√	..	√	√
28	*Zanthoxylum armatum* DC.	..	..	..	√	√

Note:

P = Legally protected under the Forest Regulations of 1995 (amended in 2001)

[I] = Species whose collection, transportation and trade is banned

[II] = Species whose export outside the country without processing is banned

[III] = Species whose felling, transport and export is banned

VU = Vulnerable according to the IUCN Red List

MPRD = Medicinal plant prioritised for research and development by DPR, 2012

MPAD = Medicinal plant prioritised for agro-technology development by DPR, 2012

= Locations for Endemic species

Aster peduncularis Wall. ex Nees subsp. *nepalensis* Grierson from Gelungkhola CF, Kavre

Himalayacalamusfimbriatus Stapletonfrom Gaikhor-1, Jhakri Khola, Gorkha

Himalayacalamusporcatus Stapleton from Dursamadu, Lepsi, Okharpani, Doti

Homaliumnapaulense (DC.) Benth.fromHile Jaljale, Kavreand Hariyali CF, Dang

Hypericumcordifolium Choisyfrom Kadampani, Gorkha and Thulo pakha CF and Kalchudegaire, Nuwakot

Rutacordata D. Donwas from Ghoda Gaun, Patmare CF, Rolpa

5.8 Forest Disturbances

Among the 433 measured forested plots in Middle Mountains, altogether 1,406 instances of forest disturbance were recorded; 6% had no impact, 42% had a minor impact, 34% had a medium impact and 18% showed major disturbances. Anthropogenic disturbances were more frequently recorded than natural disturbances. Grazing (63%), sapling and pole stage tree-cutting (42%), tree-cutting (37%) and lopping (36%) were the most commonly reported disturbances in the forest (Table 41).

Table 41: *Records of forest disturbances in the forest*

Disturbance	Intensity				Total	%
	Zero	Minor	Medium	Major		
Bush cutting	2	33	43	17	95	22
Encroachment	6	5	6	8	25	6
Forest fire	12	62	31	18	123	28
Grazing	5	107	104	56	272	63
Insect attack	2	5	6	2	15	3
Lathra cutting	4	75	64	39	182	42
Lopping	4	60	56	36	156	36
Litter collection	6	58	34	13	111	26
Land slide	13	39	19	7	78	18
Plant disease	4	0	2	0	6	1
Plant parasite	6	1	2	0	9	2
Resin tapping	7	8	17	15	47	11
Tree cutting	7	80	51	22	160	37
Wind, storm, hail, etc.	8	8	5	3	24	6
Other disturbance	4	47	39	13	103	24
Total	**90**	**588**	**479**	**249**	**1,406**	
%	6	42	34	18	**100**	

The average number of categories of disturbance per plot was four and maximum number of disturbance was fourteen. There was no disturbance in 19% of the measured plots (Figure 26).

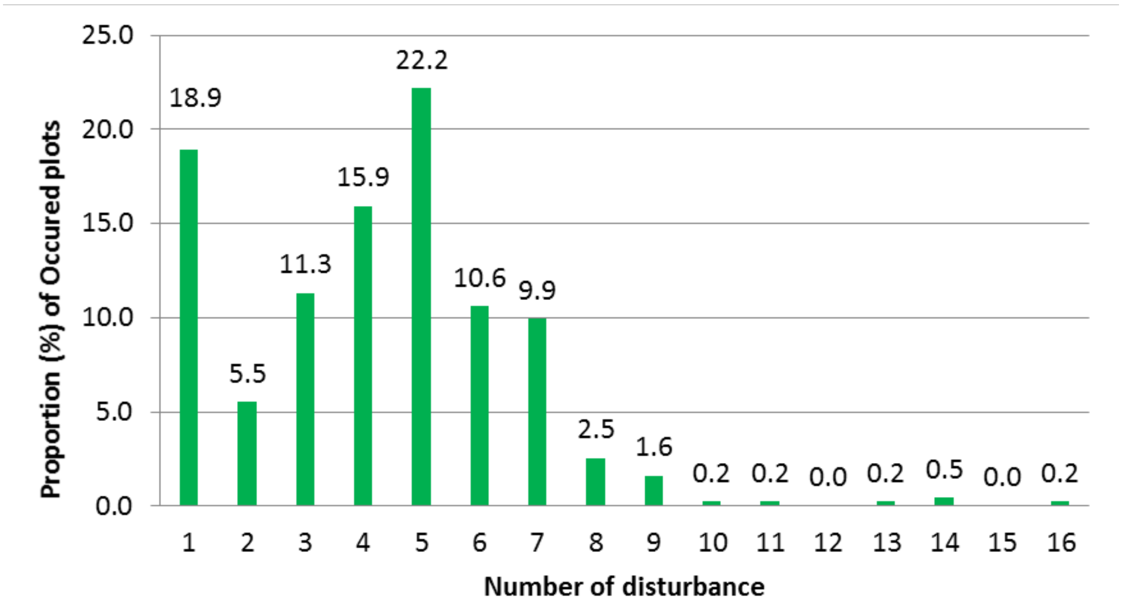


Figure 26: *Number of disturbance per plot*

Grazing was found to be the most common disturbance in all the forest types in Middle Mountains region. It was the highest disturbance factor in *Quercus* forest whereastree cutting was the highest disturbance in KS/SK forest (Table 42).

Table 42: *Proportion of forest disturbance in sample plots according to major forest types*

Disturbance	Occurrence of disturbance (%) by forest types							
	KS/SK (4)	**LMH (154)**	**Pr (168)**	**Pw (9)**	**Q (21)**	**S (63)**	**TMH (72)**	**UMH (42)**
Bush cutting	25	29	7	22	43	16	25	12
Encroachment	0	6	4	0	0	6	11	2
Forest fire	50	22	51	0	43	41	24	0
Grazing	50	64	63	67	90	52	64	57
Insect attact	0	1	1	11	5	5	4	10
Lathra cutting	25	40	28	56	52	56	49	36
Lopping	0	44	24	33	43	32	40	26
Litter collection	25	22	34	67	57	21	26	7
Land slide	0	19	24	11	38	13	18	7
Plant disease	0	1	0	0	5	2	3	0
Plant parasite	0	3	0	0	10	2	1	0
Resin tapping	0	4	54	0	5	3	1	0
Tree cutting	75	38	46	44	48	33	39	12
Wind, storm, hail, etc.	0	4	4	0	0	5	3	24
Other disturbance	0	31	21	67	10	17	15	29

Disturbances by management regime

Government managed forest had slightly higher disturbance as compared to Private forest and Community managed forest (Figure27).

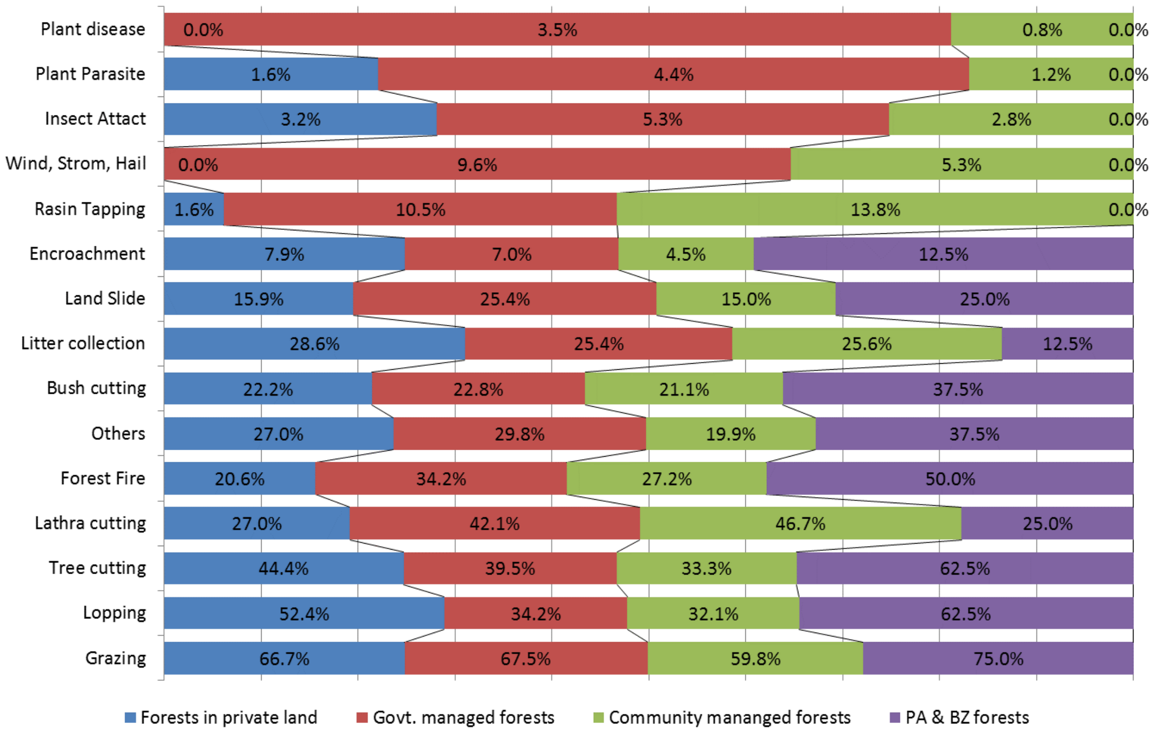


Figure 27:*Proportion of disturbance under major forest management regimes*

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ANNEX

Annex 1: Diameter-Height Model for Middle Mountain Trees of Nepal

SN	Species	Model	Equation	Parameters			Stand. Error	Adj. R^2
				a	b	c		
1	*Acacia catechu*	Michailoff	h(d)=bh+ae^(-b d^(-1))	17.580	8.590		2.543	0.50
2	*Adina cardifolia*	Wykoff	h(d)=bh+exp(a+b/(d+1))	3.503	-25.478		4.134	0.60
3	*Aesandra butyracea*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	19.812	0.491	0.491	1.777	0.87
4	*Alnus nepalensis*	Naslund	h(d)=bh+d^2/(a+bd)^2	1.587	0.186		2.479	0.84
5	*Castanopsis hystrix*	Naslund	h(d)=bh+d^2/(a+bd)^2	1.477	0.232		3.317	0.52
6	*Castanopsis indica*	Naslund	h(d)=bh+d^2/(a+bd)^2	1.901	0.224		2.485	0.75
7	*Castanopsis tribuloides*	Michailoff	h(d)=bh+ae^(-b d^(-1))	13.678	5.238		2.667	0.70
8	*Eurya acuminate*	Curtis	h(d)=bh+a(d/(1+d))^b	8.928	5.978		1.329	0.50
9	*Ficus semicordata*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.097	0.291		1.489	0.70
10	*Grewia subinaequalis*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.539	0.242		0.816	0.94
11	*Lagestroemia parviflora*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	-4.572	1.952	0.015	2.458	0.76
12	*Litsea monopetala*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.501	0.244		2.420	0.65
13	*Lyonia ovalifolia*	Naslund	h(d)=bh+d^2/(a+bd)^2	1.496	0.298		1.505	0.85
14	*Myrica esculenta*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	23.201	4.077	0.008	0.800	0.90
15	*Persea duthiei*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.135	0.234		1.763	0.84
16	*Pinus roxburghii*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	8.351	1.158	0.014	2.780	0.88
17	*Pinus wallichiana*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	2.158	0.859	0.027	1.755	0.90
18	*Quercus lanata*	Naslund	h(d)=bh+d^2/(a+bd)^2	3.823	0.187		1.987	0.80
19	*Quercus leucotrichophora*	Curtis	h(d)=bh+a(d/(1+d))^b	21.034	16.023		1.308	0.87
20	*Quercus semecarpifolia*	Wykoff	h(d)=bh+exp(a+b/(d+1))	3.183	-18.204		2.806	0.87
21	*Rhododendron arboreum*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	0.250	1.505	0.071	2.365	0.61
22	*Sapium insigne*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.348	0.235		2.095	0.79
23	*Schima wallichii*	Wykoff	h(d)=bh+exp(a+b/(d+1))	3.029	-11.292		1.455	0.92

24	*Shorea robusta*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.021	0.179		2.898	0.75
25	*Syzygium cumini*	Naslund	h(d)=bh+d^2/(a+bd)^2	1.925	0.220		1.863	0.86
26	*Terminalia alata*	Naslund	h(d)=bh+d^2/(a+bd)^2	2.978	0.157		2.417	0.89
27	Group 1*: Engelhardia* spp.	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	15.846	0.152	0.056	2.642	0.75
28	Group 2*: Quercus* spp.	Curtis	h(d)=bh+a(d/(1+d))^b	21.748	19.177		2.872	0.79
29	Group 3*: Ficus* spp.	Wykoff	h(d)=bh+exp(a+b/(d+1))	2.988	-18.154		2.508	0.75
30	Group 4*: Dyospyros* spp.	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	1.858	1.322	0.036	1.289	0.95
31	Group 5*: Symplocos* spp.	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	11.686	1.073	0.046	2.370	0.65
32	Group 6*: Rhododendron* spp.	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	-4.002	2.093	0.065	2.315	0.56
33	Group 7*: Macaragana* spp.	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	10.092	-0.168	0.055	2.574	0.79
34	Group 8*: Prunus* spp.*, Lannea coromandelica*	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	-4.265	1.877	0.030	1.751	0.86
35	Group 9*: Litsea* spp.	Naslund	h(d)=bh+d^2/(a+bd)^2	2.358	0.243		2.220	0.670
36	Group 10*: Albizia* spp.	Naslund	h(d)=bh+d^2/(a+bd)^2	2.399	0.174		3.326	0.74
37	Group 11*: Terminalia* spp.	Wykoff	h(d)=bh+exp(a+b/(d+1))	3.393	-15.500		2.168	0.91
38	Group 12: Species	Wykoff	h(d)=bh+exp(a+b/(d+1))	2.885	-10.193		3.411	0.64
39	Group 13: Species	Naslund	h(d)=bh+d^2/(a+bd)^2	2.787	0.178		3.470	0.69
40	Group 14: Species	Prodan	h(d)=bh+d^2/(a+bd+cd^2)	-3.285	2.268	0.014	3.242	0.79
41	Group 15*:* Species	Naslund	h(d)=bh+d^2/(a+bd)^2	2.387	0.227		2.475	0.71
42	Group 16*:* Species	Naslund	h(d)=bh+d^2/(a+bd)^2	1.890	0.278		1.285	0.90
43	Group 17*:* Species	Naslund	h(d)=bh+d^2/(a+bd)^2	1.795	0.273		1.494	0.84
44	Group 18*:* Species	Naslund	h(d)=bh+d^2/(a+bd)^2	2.252	0.234		0.698	0.96

Note:

h(d) = Predicted height for dbh 'd'; bh = Breast height (=1.3 m); d = Diameter at breast height

Species were lumped by genus for *Engelhardia* spp., *Quercus* spp., *Dyospyrus* spp., *Symplocus* spp., *Rhododendron* spp., *Macaragana* spp., *Prunus* spp., *Litsea* spp., *Albizia* spp., and *Terminalia* spp.

Group 12 species: *Mallotus philippensis, Madhuca longifolia, Gravillea robusta, Madhuca latifolia, Garuga pinnata, Artocarpus lakoocha, Betula utilis, Erythrina stricta, Choerospondias axillaris, Acer oblongum, Dysoxylum gobara, Pterospermum acerifolium, Michelia doltsopa, Kydia calycina, Spondias pinnata, Duabanga grandiflora, Platanus orientalis*

Group 13 species: *Bombax ceiba, Mangifera indica, Toona ciliata, Alnus nitida, Cryptomeria japonica, Michelia champaca, Anthocephalus chinensis, Alstonia scholaris, Gmelina arborea*

Group 14 species: *Cupressus torulosa, Persea odoratissima, Saurauia napaulensis, Buchanania latifolia, Anogeissus latifolius, Phyllanthus emblica, Leucaena leucocephala, Cornus oblonga, Juglans regea, Cassia fistula, Bridelia retusa, Sphaerosacme decandra, Hymenodictylon flaccidum, Cinnamomum tamala, Dalbergia sissoo, Aegle marmelos, Litchi chinensis, Artocarpus heterophyllus, Lithocarpus elegans, Knema tenuinervia, Exbucklandia populnea, Taxus wallichiana, Holoptelea integrifolia, Sloanea sterculiaceus, Cocculus laurifolius, Sorbus cuspidata, Larix griffithiana, Ceiba pentandra, Homalium zeylanicum, Ehretia acuminata, Salix babylonica, Zizyphusmauritiana, Cinnamomum glanduliferum*

Group 15 species: *Desmodium oojenense, Pyrus pashia, Cleeistocalyx operculatus, Wendlandia exserta, Nyctanthus arbortristis, Rhus wallichii, Xeromphis spinosa, Callicarpa microphylla, Neolistea umbrosa, Semecarpus anacardium, Rhus javanica, Trichilia connaroides, Elaeocarpus tectorius, Bauhinia variegata, Debregeasia salicifolia, Osmanthus fragrans, Streblus asper, Ligustrum confusum, Sorbus lanata, Fraxinus floribunda, Premna interrupta, Woodfordia fruticosa, Psidium guajava, Syzygium jambos, Bauhinia malabarica, Neolitsea cuipala, Daphniphyllum himalense, Rhus parviflora, Feronia limonia, Sterculia villosa, Acer sikkimense, Citrus maxima, Hymenodictyon excelsum, Hydrangea anomala, Aesculus indica, Acer cappadocicum*

Group 16 species: *Bauhinia purpurea*, *Casearina graveolens, Maesa chisia, Gaultheria fragrantissima, Holarrhena pubescens, Buddleja asiatica, Barberis asiatica, Coriaria nepalensis, Leucoseptrum canum, Jasminum mesneyi, Berberis aristata, Ribes glaciale, Edgeworthia gardneri, Withania coagulans, Viburum mullaha, Sarcococca coriacea, Annona squamata, Eriobotrya dubia, Buddleja macrostachya, Datura suaveolens, Wikstroemia canescens, Desmodium multiflorum, Juniperus indica, Melastoma melabathricum, Myrsine africana, Camellia sinensis*

Group 17 species: *Uraria picta, Tamarindus indica, Rhus succedanea, Phyllanthus acidum, Photinia integrifolia, Viburnum mullaha, Ficus subincisa, Ficus altissima, Boehmeria rugulosa*

Group 18 species: *Homalium napaulense, Pavetta indica, Picrasma javanica, Ribes takare, viburnum cylindricum, Viburnum erubescens, Zanthoxylum oxyphyllum, Ilex dipyrena, Lindera pulcherrima, Rhus hookeri, Prunus armeniaca*


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